Chapter 2

LITERATURE REVIEW

2.1 Introduction

The exhaustive literature survey in brief is presented in this chapter. The formulation of the research problem based on this literature survey is also presented in this chapter. This chapter reviews the investigations on monopole antennas suitable for wireless communication. Several techniques and experimental results have been found useful in understanding the monopole antennas.

2.2 Review of past work

Modern and future wireless systems are placing greater demands on antenna designs. Many systems now operate in two or more frequency bands, requiring dual or triple band operation of fundamentally narrow band antennas. These include, satellite navigation systems, cellular systems, WLAN and combination of these systems. One of the most popular antennas employed in mobile communication systems is the monopole antenna and its family.

Girish Kumar and K.P. Ray [24] in 2003 explain the simplest member of the family is the quarter wave monopole above a perfect ground plane. The impedance bandwidth achievable for the quarter wave monopole antenna is dependent on the radius of the cylindrical stub, and increases with increased radius. A simpler technique, with lower cost, is to replace the cylindrical stub of a conventional monopole with a planar element. The planar monopole antenna can be viewed as a Microstrip
antenna (MSA) on a very thick substrate with $\varepsilon_r=1$, so it gives large bandwidth.

The concept of microstrip radiators was first proposed by Deschamps [25] as early as 1953. However, the first practical antennas were developed in the early 1970’s by R.E. Munson [26] and Howell J. Q. [27]. Since then extensive research and development of microstrip antennas have been taking place. Dubost and Zisler described it more in detail in 1976. They observed the wide impedance characteristics of this antenna. Later a number of different shapes have been studied which fit into this category of broadband planar monopoles antennas. Agrawall, who proposed a formula for predicting the frequency corresponding to lower edge of the impedance bandwidth for these antennas, also studied circular and elliptical disk monopoles in 1998. The broad band planar monopoles can also be understood by considering it as a modified MSA.

Researchers have made efforts to overcome from narrow bandwidth to various configurations these have been presented in these papers [28,29,30].

Medium frequency (MF) amplitude modulated (AM) broadcast station monopole antenna has been studied by several investigators. Valentin Trainotti [31] in 1990, made measurements of ground electrical field intensity in order to obtain a coefficient for the shadow or diffraction factor. The ground E-field is of paramount importance to obtain nocturnal service of an AM broadcast station. Nocturnal service area depends on the antifading properties of the transmitting monopole antenna. Critical study of Height–radius (H/a) effect has been made in order to determine the performance of the transmitting monopole antenna. Results are interesting because they permit to evaluate what are the best H/a relationship for a determined antenna height in order to obtain maximum directivity and maximum diurnal and nocturnal service area. Improvements in existing MF AM antennas can be achieved for high fedility stereo transmissions choosing the optimum H/a relationship.
In 1990, Andrew W.C. Chu et al. [32] made an systematic investigation to determine the radiation patterns of a monopole antenna mounted on a cubical conducting box over a ground plane. The effects of the location of the monopole and the electrical size of the box were noted as compared to similar patterns measured over a flat ground plane.

A new, compact, broadband printed antenna called the tab monopole is described by J. Michael Johnson and Yahya Rahmat-Samii [33] in 1997. The tab monopole is a small antenna designed primarily for applications requiring antennas that can be readily integrated with printed circuit boards. The tab monopole is smaller than a quarter wavelengths in size but provides a 2:1 VSWR bandwidth of greater than 50%.

The circular disc monopole (CDM) antenna has been reported to yield wide-impedance bandwidth by Narayan Prasad Agrawall et al. [34] in 1998. Experiments have been carried out on a CDM that has twice the diameter of the reported disc with similar results. New configurations are proposed such as elliptical (with different ellipticity ratios), square, rectangular, and hexagonal disc monopole antennas. A simple formula is proposed to predict the frequency corresponding to the lower edge of the bandwidth for each of these configurations. The elliptical disc monopole (EDM) with ellipticity ratio of 1.1 yields the maximum bandwidth from 1.21 GHz to more than 13 GHz for voltage standing wave ratio (VSWR)<2.

Zhi Ning Chen [35] in 2000, in order to evaluate the induced currents on the surface of a cylindrical monopole antenna located over a perfectly electric conducting ground plane using cylindrical harmonics, three kinds’ fictitious walls, namely, an electric wall, magnetic walls, and a combination of both, are artificially added above the monopole. The end effect, the thickness, and the source of the monopole can be taken rigorously into account in the computations. However, introducing fictitious walls definitely changes the field distributions for the different walls. The effects of these fictitious walls on the convergence of the
impedance computations and the electric field distributions around the monopole are discussed.

The resonance frequency of broadband planar monopoles with different shapes is investigated by Marta Cabedo-Fabres et.al. [36]. A novel compact wide-band planar monopole antenna suitable for use in multi-service wireless devices is proposed. By adding a shorting pin to an arrow tip planar monopole, a great improvement in the bandwidth performance is achieved, while retaining good radiation characteristics.

Gamal Soegiono and Andre' Kesteloot [37] studied the shortened monopole described herein is based on a commercial antenna developed by OE7OKJ, but constitutes a special version, tailored for radio amateurs. Permission is granted for public and private usage and experiments. Commercial applications are covered by patents.

A broad-band U-slot rectangular patch antenna printed on a microwave substrate is investigated by Kin-Fai Tong et.al. [38] in 2000. They have taken dielectric constant of the substrate is 2.33. The antenna is fed by a coaxial probe. The characteristics of the -slot patch antenna are analyzed by the finite-difference time-domain (FDTD) method. The maximum impedance bandwidth achieved is 27%, centered around 3.1 GHz, with good pattern characteristics.

Zhi Ning Chen [39] in 2000, experimentally investigated the input impedance of tilted planar monopole antennas with different shapes. The effects of the different oblique angles between the planar element and the vertical on the input impedance and resonant frequency are discussed.

Fan Yang et.al. [40] in July 2001, presents a novel single-patch wide-band microstrip antenna: the E-shaped patch antenna. Two parallel slots are incorporated into the patch of a microstrip antenna to expand it bandwidth. The wide-band mechanism is explored by investigating the behavior of the currents on the patch. The slot length, width, and
position are optimized to achieve a wide bandwidth. The validity of the design concept is demonstrated by two examples with 21.2% and 32.3% bandwidths. Finally, a 30.3% E-shaped patch antenna, resonating at wireless communication frequencies of 1.9 and 2.4 GHz.

Z. Shen and R.H. Macphie [41] in 2001, presents a numerical technique based on the modal-expansion method for modeling a multislave monopole antenna fed through an infinite ground-plane by a coaxial transmission line. The modal-expansion analysis is facilitated by introducing a perfectly conducting boundary at a variable height over the ground-plane of the monopole. The resulting structure is then divided into a number of regions and the electromagnetic field components in each region are expanded into the summation of its modal functions. The current distribution over the monopole and sleeve surfaces as well as the antenna's input impedance are computed by finding the expansion coefficients through matching the tangential field components across the regional interfaces.

Gwo-Yun Lee et.al. [42] studied the low-profile planar monopole antennas capable of 900 and 1800 MHz dual-frequency operations are very attractive for GSM/DCS mobile phone applications. Many related promising designs have also been demonstrated recently. These designs include modifying the geometry of a bent folded monopole/loop antenna, folding a meandered printed strip, using two or three meandered printed strips, and so on. In this paper, they proposed another planar monopole antenna design with a very low antenna height less than 0.04l0 (the total antenna height is only 12 mm for operating in the 900-MHz band). In addition, the antenna is capable of triple-band operation, covering the GSM, DCS and PCS bands.

Dual-band designs of the inverted-L monopole antenna loaded with a meandered wire or a helix for applications in GSM/DCS dual-band mobile phones are presented by Hao-Chun Tung et.al. [43] in 2002. In the designs, the inverted-L monopole is operated as a
quarter-wavelength structure for 1800 MHz operation. The meandered wire or the helix is also operated as a quarter-wavelength structure, and however, is for 900 MHz operation. In addition to two separate wide bandwidths obtained for the proposed designs, the antenna’s height from the ground plane is only about 14 mm or 4.2% of the wavelength at 900 MHz. This low-profile advantage makes the proposed designs very promising to be integrated within the mobile phone housing, similar as the design in, leading to no protruded antenna in appearance for mobile phones.

Rajender Singh and Prof. Girish Kumar [44] says that broadband planar monopole antennas have all the advantages of the monopole in terms of their cost, and ease of fabrication besides, yielding very large bandwidths. For many applications large bandwidth is required. Recently, many techniques to tailor and optimize the impedance BW of these antennas have been investigated. These include the use of bevels, slots and shorting posts. These antennas are becoming popular, and have been proposed for modern and future wideband wireless applications. The radiation performance is also shown to be acceptable over a wide range of frequency. These antennas have been reported to provide multi band characteristics too. More recently, it has been shown that, although the square monopole (SM) provides smaller BW than the circular monopole (CM), its radiation pattern suffers less degradation within the impedance BW. Investigations on planar monopoles of different geometrical shapes, such as the ellipse, rectangle, bow tie, diamond and trapezoid have since been conducted.

Due to their simple structure and omnidirectional radiation, monopole antennas have been found widespread applications in mobile communication systems is explained by Horng-Dean Chen et.al. [45] in 2003. To meet the miniaturization of modern mobile communication equipments, the design of compact monopole antennas is of particular importance. The proposed antenna is fed by a CPW line and is printed in a single metal layer. Therefore, this antenna can be manufactured in a
simple procedure. Moreover, due to the presence of an extended conductor line in the proposed design, the antenna is not only capable of providing the GSM/DCS dual-frequency operations, but also can have an antenna-size reduction at a given dual-frequency operation.

A new wide-band shorted planar monopole with a bevel is presented by M.J. Ammann and Zhi Ning Chen [46] in April-2003. The numerical simulations and measurements demonstrate that the impedance bandwidth of a wide-band planar square monopole is shown to increase dramatically by combining beveling and a shorting technique.

Horng-Dean Chen et.al. [47] in 2003 proposed an antenna is fed by a CPW line and is printed in a single metal layer. Therefore, this antenna can be manufactured in a simple procedure. Moreover, due to the presence of an extended conductor line in the design, the antenna is not only capable of providing the GSM/DCS dual-frequency operations, but also can have an antenna-size reduction at a given dual-frequency operation.

Max Ammann [48] in 2003, future software defined and reconfigurable radio networks are required to separate in multiple, wide-ranging, frequency bands, which place heavy demands on antenna designs. Rather than using antennas tuned to operate in certain predefined frequency bands under predefined radio systems at the time of manufacture, which limits the possibilities of implementing new radio systems on a reconfigurable terminal, a wideband antenna is proposed.

For the purpose of wideband operations, a printed monopole antenna fed by a microstrip line is investigated by Mohamed H. Al Sharkawy et.al. [49]. A single element is studied before using it to form a linear array or two-dimensional antenna array system. The antenna element has a single T-shaped radiator fed by a microstrip line. This design is found to be useful for the entire C-band frequency range
centered at 6 GHz. The computed return loss is presented that shows a bandwidth of 77%, with 50 Ω input impedance.

Prototypes of the antenna designed for WLAN operations in the 2.4 and 2.5 GHz bands have been constructed and tested by W.C. Liu and C.M. Wu [50]. A rectangular notch is introduced to obtain a broadband dual frequency operation of a planar monopole antenna fed by a coplanar waveguide (CPW). The antenna is printed on a single metal layer and therefore is easily constructed.

Dual and wideband aperture-stacked patch antenna is presented by K. Oh et.al. [51] in 2004. It consists of a single microstrip patch, which is notched on the radiating patch to obtain dual-band operation and two dielectric substrates and a foam material. By the proper choice of the aperture size and height of a foam material, dual and wideband characteristics could be realized.

Nordic Semiconductor ASA [52] taking the demand for easy fabrication and low cost into account in the development of low power radio devices for 868 /915MHz applications. A quarter wavelength monopole antenna implemented on the same printed circuit board as the radio module is a good solution. A printed quarter wavelength monopole antenna is very easy to design and can be tuned simply by slight changes in length. This presents basic guidelines on how to design such an antenna for use together with the nRF905 and nRF9E5 Single chip Transceivers operating in the 900MHz frequency range.

A square planar metal-plate monopole antenna fed by using a novel trident-shaped feeding strip is presented by Kin-Lu Wong et.al. [53] in 2005. With the use of the proposed feeding strip, the square planar monopole antenna studied shows a very wide impedance bandwidth of about 10 GHz (about 1.4–11.4 GHz, bandwidth ratio about 1:8.3), which is larger than three times the bandwidth obtained using a simple feeding strip (about 1.5–3.3 GHz, bandwidth ratio about 1:2.3). In addition, the
proposed feeding strip can be integrated with the square planar monopole, that is, the feeding strip and the square planar monopole together can be easily fabricated using a single metal plate, making the proposed antenna easy to construct at a low cost.

In 2005, C. S. Shin et al. [54] designed a meander-line planar monopole antenna mounted on PCS/IMT-2000/WLAN handset for SAR reduction. Frequency characteristics and SAR value optimized with various design parameters are analyzed and designed. Designed internal monopole antenna mounted on the handset is simulated. The 1 g and 10 g peak average SARs of the internal monopole antenna are 0.656 and 0.387 W/kg respectively. And the internal monopole antenna and external monopole antenna attached on the handset are tested. As a result, the 1 g and 10 g peak average SARs of the internal monopole antenna are 0.686 and 0.356 W/kg. And results the external monopole antenna are 1.33 and 0.812 W/kg, respectively. So the internal monopole antenna has a about 50 % reduced SAR value in comparison with external monopole antenna.

Jihak Jung et al. [55] in 2005 presents a small microstip-fed monopole antenna, which consists of a rectangular patch and a truncated ground plane for ultra-wideband application. The proposed antenna is designed to operate over 3.1 to 11 GHz for $S_{11}<-10$ dB.

In 2005, M. John and M.J. Ammann [56] describes a printed rectangular-plate monopole fed by microstrip line. The effect of varying the plate width, feed gap height, and feedline width on the impedance bandwidth is examined. It is shown that for a fixed ground-plane size, that optimization of these parameters can yield an impedance bandwidth ratio of 4.3:1, without using any broadbanding techniques.

A novel and compact ultra-wideband (UWB) microstrip-fed monopole antenna having frequency band notch function is presented by Kyungho Chung et al. [57] in 2005. To increase the impedance
bandwidth of an antenna, a narrow slit is used. By inserting a modified inverted U-slot on the proposed antenna, the frequency band notch characteristic is obtained. The designed antenna satisfies the voltage standing wave ratio requirement of less than 2.0 in the frequency band between 3 and 11 GHz while showing the band rejection performance in the frequency band of 5.0 to 5.9 GHz.

A multiple band-notched planar monopole antenna for multiband wireless systems is presented by Wang-Sang Lee et al. [58] in 2005. The proposed antenna consists of a wideband planar monopole antenna and the multiple U-shape slots, producing band-notched characteristics. In order to generate two band-notched characteristics, they proposed that three U-shape slots are required. This technique is suitable for creating ultra-wideband (UWB) antenna with narrow frequency notches or for creating multiband antennas.

A novel multi-band printed antenna, ideal for all IEEE 802.11 wireless local area network (WLAN) systems, is presented by Yuehe Ge et al. [59] in 2005. It operates well in all frequency bands (2.45, 4.9, 5.25 and 5.775 GHz) allocated worldwide for IEEE 802.11a, b, g and j wireless computer systems, demonstrating a return loss $> -10$ dB, an excellent efficiency and a wide radiation pattern. The antenna is printed on a thin (0.8 mm), low cost substrate FR4 using standard microstrip fabrication techniques at a very low cost, and hence it does not require extra processes for mounting or connecting it to the transceiver board. It’s very small footprint area (only 10x10 mm) makes it the smallest quad-band WLAN antenna available yet.

A Novel internal triple band folded planar antenna is introduced by C.H. See et al. [60]. By modifying the geometry and implementing the shorting pins onto two sides folded structure rectangular patch antenna. The size of the folded rectangular patch antenna can be successfully reduced to volume of 34X3Xh7 mm. An additional microstrip line of 2X8 mm is also incorporated with the proposed patch antenna in order to
achieve the impedance bandwidth of 29.7% (return loss-10dB) which is covering the DCS1800, PCS1900 and UMTS2000, while it is mounted on a finite ground plane of 50X100mm. The typical characteristic of the proposed antenna such as impedance bandwidth and far field radiation patterns is discussed theoretically and experimentally. The simulated and measured results are indistinguishable. Besides, the theoretical analysis of the tuning effects of the geometry parameters on impedance matching is also investigated.

In 2005, Q. Sui C. et.al. [61] focuses on λ/4 monopole antennas located in a meta-material that exhibits simultaneously negative values of effective permeability and permittivity within a microwave frequency band, as well as our experimental study in an anechoic chamber. The experimental results show that the electromagnetic waves radiated by the monopole are negatively refracted at the interface between the meta-material and the air at certain directions. In addition, the radiation pattern of the monopole in the meta-material is directional while it is non-directional without the meta-material.

J.S. Kuo and C.Y. Huang [62] presents in March-2006 that, a side-feed planar monopole antenna capable of triple frequency operation at about 900, 1800 and 1900 MHz. The planar monopole antenna can be side-fed and mounted perpendicularly to the main circuit board of a communication device so that it offers a novel design with a free degree of feed point so as to save device space, resulting in a low profile to the system ground plane. In addition, the obtained impedance bandwidths of the proposed antenna at about 900, 1800 and 1900 MHz can cover the GSM (890–960 MHz), DCS (1710–1880 MHz) and PCS (1850–1990 MHz) bands.

In November-2006, M. Ferrando-Bataller et.al [63], in order to obtain a clear insight into the physical performance of planar monopole antennas, several of them are analyzed by means of the Theory of Characteristic Modes. The investigation is focused on the influence of the
planar shape in the impedance bandwidth of the antenna. It will be demonstrated that the impedance bandwidth is extremely dependent on the feeding gap configuration. Next, a printed rectangular planar monopole antenna with two feeding points will be proposed for UWB applications. Preliminary results obtained for this antenna show that it exhibits good radiation behavior within the UWB frequency range.

An internal modified monopole antenna for DVB-H band is presented by D.H. Choi et.al. [64]. By extending the feeding line of the modified monopole and locating it over a ground plane, a wideband input impedance of 328 MHz within 6:1 VSWR is achieved. The proposed antenna has an approximately omnidirectional radiation pattern and yields greater than 3 dBi antenna gain covering DVB-H band. These features are suitable for DVB-H applications.

In 2006 A.A. Eldek [65] presents a planar microstrip-fed tab monopole antenna for ultra wideband wireless communications applications. The impedance bandwidth of the antenna is improved by adding slit in one side of the monopole, introducing a tapered transition between the monopole and the feed line, and adding two-step staircase notch in the ground plane. The proposed antenna has a small size of 16×19 mm, and provides an ultra-wide bandwidth and good radiation characteristics to satisfy the requirements of the current and future wireless communications systems.

Chi-Hun Lee and Seong-Ook Park [66] in 2006 proposes a compact printed hook-shaped monopole antenna for 2.4/5-GHz WLAN applications. The designed antenna has a compact size with dimensions 26 X10X1mm³. The impedance bandwidth (VSWR<2) of the proposed antenna is about 170MHz (2.32–2.49 GHz) for 2.4-GHz (Bluetooth) bands and 4500 MHz (4.4 – 8.9 GHz) for the 5-GHz (WLAN) bands. The radiation patterns are nearly omnidirectional, which is similar to typical those of monopole antenna.
C. Y. Wu et al. [67] proposed a novel surface-mount ultra-wideband (UWB) monopole antenna with a compact size of only 12.5 X 9 X 1.5 mm$^3$ is obtained by folding a metal-plate onto a low-profile rectangular-box foam base. By carefully adding a matching slit on the upper side of metal-plate, the antenna can achieve good impedance matching over a very wide bandwidth of about 7.97 GHz (3.03-11.0 GHz, defined by 2:1 VSWR).

In 2006, Giuseppe Ruvio and Max J. Ammann [68] presented in this paper are shown to have a fractional impedance bandwidth up to 111% (4.0 GHz to 10.5 GHz) for a -10dB return loss. Extreme compactness, large impedance bandwidth and stable omnidirectional radiation pattern are the most important features of this novel radiation element and make it a valuable product for broadband, in-door, mobile or vehicular purposes.

J. Liang et al. [69] in 2006 presents a study of elliptical disc monopole fed by microstrip line for ultra wideband (UWB) applications. The design parameters for achieving optimal performance are analyzed. The antenna characteristics are also discussed.

A planar monopole antenna with a staircase shape and small volume (25X26X1)mm$^3$ is proposed by Young Jun Cho et al. [70] in 2006. With the use of a half-bowtie radiating element, the staircase-shape, and a modified ground plane structure, the proposed antenna has a very wide impedance bandwidth measured at about 11.6 GHz (2.9–14.5 GHz, bandwidth ratio about 1:5) below VSWR 2 including the WLAN band notched in the vicinity of 5 GHz. An omnidirectional radiation pattern is obtained.

A small microstrip-fed monopole antenna using an L-shaped notch is presented by Jihak Jung et al. [71] in 2006 for ultra-wideband applications. The proposed antenna, with compact size of 15.5×21 mm$^2$ including the ground plane, is designed to operate over the frequency
band between 3.05 and 10.9 GHz for $S_{11}<-10$ dB. Good return loss and radiation pattern characteristics are obtained in the frequency band of interest.

In 2006, Joeri R. Verbiest and Guy A. E. Vandenbosch [72] presents a novel antenna topology based on the printed tapered monopole antenna (PTMA) is investigated in view of ultra-wideband (UWB) wireless body area network (WBAN) applications. First, the bandwidth in the presence of a human arm is studied. Second, the pulse distortion of a modulated Gaussian pulse is investigated, based on measured 21-parameters. They observe that there is a small acceptable influence on the matching of the antenna and that the pulse distortion is low. The main conclusion is that this modified PTMA is a very good candidate for WBAN UWB applications.

Juan Valenzuela-Valdes et.al. [73] says that, the advance of communication systems requires new antenna designs to comply with the ever-increasing demands of the wireless market. The antenna designs are being conditioned by miniaturization and migration to new frequencies (IEEE 802.11a/g), while keeping compatibility with other systems poses yet additional constrains. This contribution presents a novel monopole multi-band printed antenna design for Wi-Fi systems, featuring the use of a spurline filter to obtain dual-frequency operation.

In 2006, Jieh-She Kuo et.al. [74] proposed a novel design concept of planar monopole antenna with a side-feed method, which is simple and different from that reported in. We demonstrate that a novel side-feed to planar monopole antenna is also a candidate for triple-frequency operation in fashion mobile communication devices. The proposed triple-frequency planar monopole antenna feed at the side-plane which compact the communication device space and is easy to construct at low cost by the material of thin copper. With a small area of 6 x 31mm to the proposed planar monopole antenna can achieve two separate, wide, resonant modes at about 900, 1800, and 1900 MHz, covering the
required bandwidths of cellular systems in use for mobile communications worldwide: GSM (890–960 MHz); DCS (1710–1880 MHz); and PCS (1850–1990 MHz).

Joonil KIM et. al. [75] in 2006, presents a wideband CPW (coplanar waveguide)-fed Li-shaped monopole antenna for WLAN 802.11 in ISM band. The CPW-fed monopole antenna consists of an L-shaped folded monopole and an I-shaped tuning stub which is simply connected at the end of a coplanar waveguide feed line. The wideband operation of the antenna is originated by two resonant frequencies of the L-shaped folded monopole. The optimized length of the I-shaped tuning stub reduces VSWR below 2 between the two adjacent resonant frequencies. The measured results of the proposed antenna show that the impedance bandwidth is 6.6GHz (3.8GHz-10.4GHz) and exhibit omni-directional radiation patterns in H-plane.

A novel internal monopole antenna with integrated shielding case for application in mobile phone is presented by Chia-Lun Tang et.al. [76]. The proposed antenna module is constructed from a single metal plate that is folded into a shape that provides both a RF shielding case covers an RF front module and a dual-band monopole antenna applies for GSM and DCS band operating. By this high integration antenna design, the antenna will not need any more isolation distance for getting good impedance bandwidth, thus the antenna has a compact size and is placed closed to the RF shielding case. In this paper, the GSM/DCS dual-band internal monopole antenna has been realized into a mobile phone Nokia 3310, and the cost and size of the proposed antenna will be better than the original antenna design (planar inverted-F antenna) of Nokia 3310.

In 2006, B. Kim et.al. [77] proposed a curvature CPW-fed ultra-wideband monopole antenna on LCP substrate. The proposed antenna has good performance over the entire UWB frequency range (3.1–10.6GHz), which enhanced the impedance bandwidth by adding four
notches on rectangular patch. It can be easily mounted in conformal shapes (e.g. cylindrical), because LCP substrate have many attractiveness, especially flexible characteristic, for use in many mm-wave areas.

The analysis of a new printed antenna is presented by V Zachou et.al. [78] in the year 2006. This antenna consists of a printed monopole, with one or two sleeves on each side, fed by a coplanar waveguide (CPW) line. Switches are used to control the length of the monopole and the sleeves and to tune the resonant frequencies of the antenna. In the case of the double-sleeved antenna, the switch is used to connect or disconnect a second sleeve in the cactus antenna. Measurement results show that the cactus antenna maintains the dipole-like radiation patterns for all the different resonant frequencies.

An optimized design for the rectangular printed monopole antenna with a slitted ground plane is presented by X.L. Bao and M. J. Ammann [79]. A parametric study of antenna parameters, including the length and width of the ground plane, the length and width of the rectangular plate, and the gap between the patch and ground plane is presented. A slit in the ground plane is shown to reduce the lower-edge frequency and improve the bandwidth. A parametric study of the slit is given.

Jana Jilkova and Zbynek Raida [80] provides an experimental comparison of four types of ultra-wideband coplanar-fed planar monopole antennas. Parameters of the open stub completed by an L-shaped monopole and the cross monopole were adopted from the literature. Monopoles were compared from the viewpoint of the impedance bandwidth, gain, directivity patterns and dimensions.

A method for the design and optimization of wideband printed planar monopoles using a genetic algorithm is presented by Matthias John and Max J. Ammann [81]. This novel technique employs overlapping sub-patches which ensures electrical contact in such
constellations where two sub-patches are touching only at the corner, hence reducing losses. The method was used to design a wideband monopole antenna with application in higher cellular, WLAN and UWB. Furthermore, the technique is modified for multigoal optimization to achieve multiple bands and reduce the lower edge frequency. The best solutions were prototyped and a full experimental evaluation was made.

A compact planar antenna for multisystem applications has been designed and manufactured by Anna Miskiewicz and Marek Kitlinski [82]. A modified feeding method has been used to meet the requirements of modern telecommunications devices. It has been shown, that by adjusting the size of the rings, required allocation of bands is possible. The proposed antenna is suitable for ISM band devices and gives perspectives for multi-standard operation.

A. Mohamed and L. Shafai [83] in 2007, study the performance of square, circular, elliptical Ultra wideband (UWB) loop monopole antennas. Both impedance and radiation pattern bandwidths of these antennas are studied and compared. The effect of changing conductor widths on the impedance bandwidth for each loop monopole antenna is then studied to find the appropriate width that gives an UWB impedance bandwidth over the frequency band of 3.1 to 10.6GHz.

In 2007, Chengwei Qiu et.al. [84] first present, a hybrid shape adopted for the planar monopole antenna, which has UWB operating bandwidth and band-notch feature. At the center notch frequency. The disturbance of surface current distribution in this hybrid patch will be smaller compared to the conventional rectangular or square patch, thus can smaller mismatch of the antenna’s input impedance. Hence, the performance of the UWB antenna is improved.

A novel compact ring monopole antenna with double meander lines is proposed by G. Zhao et.al. [85] in 2007 for wireless local area networks (WLAN) applications in IEEE 802.11b/g/a systems. The designed
antenna, fed by a 50 Ω microstrip transmission line, is only 32 mm in height and 16 mm in width. By introducing a horizontal and a vertical branched strip to a closed rectangular strip ring, the proposed antenna can generate two separate impedance bandwidths.

A dual band coplanar waveguide (CPW)-fed planar monopole antenna suitable for WLAN application is presented by W. C. Liu [86] in 2007. The antenna resembling as a “G” shape and optimally designed by using the particle swarm optimization (PSO) algorithm can produce dual resonant modes and a much wider impedance bandwidth for the higher band. The measured results explore good dual band operation with −10 dB impedance bandwidths of 9.7% and 62.8% at bands of 2.43 and 4.3 GHz, respectively, which cover the 2.4/5.2/5.8 GHz WLAN operating bands, and show good agreement with the numerical prediction.

R. Zaker et.al. [87] presents a novel modified Printed Tapered Monopole Antenna (PTMA) for ultra wideband (UWB) wireless communication applications. The proposed antenna consists of a truncated ground plane and two-tapered radiating patch separated by a slot (air gap) of different slopes, which provides a wideband behavior and relatively good matching. Moreover, the effect of a modified T-shaped slot inserted in the first tapered patch, on the impedance matching is investigated. The antenna has a small area of 23×26.5mm² and offers an impedance bandwidth as high as 100% at a Centre frequency of 7.2 GHz for S11 <−10 dB, which has an area reduction of 15% and a frequency bandwidth increment of 72% with respect to the previous similar antenna.

In the year 2007, Quanixin Wang et.al. [88] studied modal-expansion method is employed to analyze an array of multiple monopole antennas. A perfectly conducting plate is introduced at the top of the monopole array to facilitate the modal-expansion analysis. Expansion coefficients in the field expressions are found by enforcing continuity conditions of the tangential field components across the regional surfaces. Cylindrical function’s addition theorem is employed to realize
the transformation of field expressions in different coordinate systems. Numerical results for the S-parameters of a two-monopole antenna are presented and they are in good agreement with experimental ones. Also examined is the effect of the distance between two monopoles on the antenna’s mutual coupling and radiation pattern. A four monopole antenna is studied for its beam-steering capability and simulated results for its radiation properties are compared with those obtained by high frequency structure simulator (HFSS).

A wideband, compact planar monopole antenna having a 2:1 VSWR bandwidth of 98% (1.68 GHz–4.9 GHz) is presented by P.C. Bybi et.al. [89] in 2007. The omnidirectional radiation pattern with moderate gain and linear polarization in the entire band makes the antenna an excellent candidate for new generation mobile applications. Details of the antenna design and a comparison of simulated and measured results are presented and discussed.

In 2008 K.P. Ray [90] presents the design equations for lower band-edge frequency for all the regular shapes of printed monopole antennas with various feed positions. The length of the feed transmission line is a critical design parameter of these monopole antennas. Design curves for the length of the feed transmission line for various lower band-edge frequencies for all these regular shaped monopoles have been generated.

A printed ultra wideband (UWB) monopole antenna is proposed by A. A. Pramudita et.al. [91] for applications on stepped frequency continuous wave (SFCW) ground penetrating radar (GPR) within a frequency range of 100–1000 MHz. The proposed antenna consists of a hexagonal strip line with resistive loading and a rectangular slot that is added to the ground plane side of the printed antenna implemented on FR4 epoxy materials. The resistive loading at the hexagonal monopole is effective to increase bandwidth in the higher frequency region, while the rectangular slot is used to improve bandwidth characteristic in the lower
frequency region. This paper investigates the characteristic improvement in the lower frequency region by applying a parametric study on the rectangular slot that is added at the ground plane side of the UWB monopole antenna.

Chieh-Hsien Wu and Kin-Lu Wong [92] presents an internal shorted planar monopole antenna embedded with a resonant spiral slot for GSM850/900/DCS/PCS/UMTS operation in the mobile phone. The planar monopole is printed on an FR4 substrate of small size 10X45 mm$^2$, and a spiral slot of length 108 mm is embedded therein. The planar monopole is then placed above and perpendicular to the top edge, with a small distance of 7 mm, of the system ground plane of the mobile phone to operate as an internal antenna. A coupled feed printed on the top no-ground portion of the system circuit board is used to excite both the planar monopole and the spiral slot to generate two wide bands covering GSM850/900 and DCS/PCS/UMTS operation, respectively. The antenna is also suitable to integrate with the associated electronic components, such as the speaker, to achieve a compact integration of the antenna inside the mobile phone.

The design of a printed monopole antenna on the system circuit board of the mobile phone for achieving GSM850/900/1800/1900/UMTS operation with a small area of 10 mmX60 mm is presented by Kin-Lu Wong and Ting-Wei Kang [93] in 2008. The antenna is easy to fabricate at low cost and mainly comprises a driven strip, a coupled strip, and a high-pass matching network for providing two wide operating bands at about 900 and 1900 MHz to cover GSM850/900 and GSM1800/1900/UMTS operations, respectively. The wide lower band is controlled by the driven strip excited as a quarter-wavelength mode, which is further tuned to become a dual-resonance excitation by incorporating the high-pass matching network for effective bandwidth enhancement. For the wide upper band, it is formed by a quarter-wavelength mode excited at about 1800 MHz by the coupled strip and the higher-order mode contributed by the driven strip.
In 2008, Fallahi et.al. [94] presents a novel band-notched elliptical slot antenna for Ultra Wide-Band (UWB) communication, which is printed on a dielectric substrate of RT-duroid 6006 with relative permittivity ($\varepsilon_r$) of 6.0, thickness of 1.27 mm, and fed by an elliptical open ended microstrip line connected to the 50 $\Omega$ main line. This antenna is designed to be used in frequency band of 3.1–10.6GHz. Band notched characteristics of antenna to reject the frequency band of 5.15–5.825 GHz, which is limited by IEEE 802.11a, is realized by parasitic inverted-U strip attached to the elliptical slot plane. Effects of varying the parameters of parasitic inverted-U strip on performance of proposed antenna have been investigated.

M. Naghshvarian-Jahromi [95] presented a compact band-notched UWB planar antenna with Transmission-Line-fed is presented and I'm using a new technique by etching a narrowband resonance H-shape slot in the ground plane of the antenna. This antenna is capable reducing the interference at the WLAN bands by eliminating the 4.85–6.17 GHz band. The proposed antenna has compact size of 16×22 mm$^2$ including the ground plane and because of miniature dimensions, good radiation patterns with monopolar characteristics are obtained in the frequency band of interest i.e., at least 10 dB isolation exists between co-polarization and cross-polarization.

Design and analysis of a novel broadband V-shaped monopole antenna is presented by A.A. Dastranj et.al. [96] in 2008. The proposed antenna has a simple configuration to fabricate with low cost. The antenna is composed of two elliptical conducting plates connected to the two edges of a small horizontal rectangular plate and placed over a small circular ground plane. The designed antenna has a very wide bandwidth range of 3–18 GHz, low cross polarization, relatively high gain and good far-field radiation characteristics in the entire operating bandwidth. To obtain the broad bandwidth, the antenna dimensions have been optimized. A comprehensive parametric study has been carried out to understand the effects of various parameters and to optimize the
performance of the final design. The designed antenna is simulated with software packages CST microwave studio and Ansoft’s HFSS in the operating frequency range.

An ultra-wideband (UWB) U type monopole antenna fed by a coplanar waveguide (CPW) is proposed by X.C. Yin et.al. [97] in 2008. It has low profile and very compact size (14.48mm×28.74mm×0.8 mm). It provides a wide impedance bandwidth ranging from 3.08 GHz to about 12.75 GHz adjustable by variation of its parameters, such as the relative permittivity and thickness of the substrate, width, and feed and ground plane dimensions. Parametric study is presented.

J.S. Mandeep and T. C. How [98] in 2008 presented wideband dual-frequency folded dual monopole antenna. By the proper choice of the dimensions of the Y-shape patch and the gap distance for the feeding structure, an additional resonant mode and wide impedance matching can be realized. Both simulated and experimental results, such as antenna impedance bandwidth, antenna radiation characteristic, and antenna gain have been presented and discussed.

R.A. Bhatti and S.O. Park [99] in December-2008 proposes a low-profile monopole antenna covering the following frequency bands is for mobile phone applications: Global System for Mobile Communications (GSM-900), Digital Communication System (DCS), Personal Communication Services (PCS), Universal Mobile Telecommunications System (UMTS), Wireless Broadband (WiBro), Bluetooth, Satellite-Digital Multimedia Broadcasting (S-DMB), and Wireless Local Area Network (WLAN) frequency bands in the 5.0 GHz range. Multiple resonators in a compact configuration have been used to realize the octa-band internal antenna within a volume of 2.08 cm that is very attractive for multifunctional slim handsets.

A small printed monopole antenna for ultra wide band applications is proposed by Priyadarshi Suraj and Vibha Rani Gupta [100] in
November 2009. The shape of the radiating patch considered is rectangular. The effect of the current distribution has been studied. The patch configuration is then modified to improve the impedance bandwidth. The dimensions of the patch and the distance between ground plane and radiating patch are optimized using the Genetic Algorithm.

A simple and compact coplanar waveguide (CPW)-fed ultra-wideband (UWB) monopole-like slot antenna is presented by X. Qing Z.N. Chen [101] in 2009. The proposed antenna comprises a monopole-like slot and a CPW fork-shaped feeding structure, which is etched onto an FR4 printed circuit board (PCB) with an overall size of 26 mmX29 mmX1.5 mm. The simulation and experiment show that the proposed antenna achieves good impedance matching, consistent gain, stable radiation patterns and consistent group delay over an operating bandwidth of 2.7 –12.4 GHz (128.5%). Furthermore, through adding two more grounded open-circuited stubs, the proposed antenna design features band-notched characteristic in the band of 5 –6 GHz while maintaining the desirable performance over lower/upper UWB bands of 3.1 –4.85 GHz/6.2 –9.7 GHz.

The characteristics of an ultra-wideband (UWB) planar monopole antenna with multiple simple slots are presented by B. Rahmati and H. R. Hassani [102]. By placing a pair of symmetrical horizontal slots on the sides of the monopole antenna a tune-able notch characteristic can be obtained. The length, width and height of the slot can be used to tune the center frequency, bandwidth and reflection coefficient of the notch. Placing two pairs of horizontal slots on the sides of the monopole antenna two tune-able notched characteristics can be obtained. Based on slot length and slot position an approximate formula for the notch Centre frequency is given.

A novel printed top-loaded monopole antenna with a pair of sleeves on the ground plane for multiband wireless local area network
(WLAN) applications is presented by J. Chen et.al. [103]. This antenna is composed of a top-loaded monopole and two sleeves on a ground plane. Both the antenna and the ground plane are printed on the same side of an inexpensive FR4 substrate. The operation bandwidth of this proposed antenna covers 2.4 GHz/5.2 GHz/5.8 GHz WLAN bands and 7.4 GHz-8.8 GHz for UWB application, which perfectly meet the requirement of multiband working.

Z. Behjati and M. N. Azarmanesh [104] present a modified semi-elliptical monopole antenna with a two-branch feed line and dual band-notched filter structure for UWB applications. By adjusting the parameters of the proposed antenna an UWB impedance bandwidth with a very good impedance matching can be achieved. The designed antenna operates over the frequency band between 2.7 to 11 GHz, rejecting the undesired frequency bands from 3.3 to 3.8 GHz and 5.1 to 5.85 GHz.

Two planar monopole antennas with wide impedance bandwidth are designed by Y. Chen et.al. [105]. A full-wave method of moment (MOM) based on the electric field integral equation (EFIE) is applied to analyze the impedance bandwidth and radiation performance of the monopoles. Meanwhile, the multilevel fast multipole algorithm (MLFMA) is employed to reduce the memory requirements and computational time. Experimental results such as the impedance bandwidth and radiation patterns are presented. The good agreement between the experimental and numerical results well demonstrates the efficiency and accuracy of the MLFMA code. Both the experimental and numerical results show that the two planar monopole antennas possess good input impedance and radiation performance over the AMPS, GSM900, and DCS band. As the proposed antennas can achieve such wide impedance bandwidth with relatively low profile, they are very suitable for multi-band mobile communication systems.

Design of a CPW-fed monopole antenna for multi network application is presented by Wen-Chung Liu et.al. [106]. The radiation
mechanism of such an antenna has been investigated, based on a moment-method numerical analysis and experimental measurement. The antenna with a pentagonal patch and an inverted U-shaped strip is fed by a CPW structure and can excite multi resonance modes, which therefore provide dual continuous frequency bands, to cover the GPS L1 band, 3.5/5.5 GHz Wi-MAX bands, and 5.2/5.8 GHz WLAN bands. The effects of the pentagonal patch with different added loads are analyzed and the prototype of optimized design has been constructed and measured.

Chow-Yen Desond Sim et.al. [107] proposed an octagonal monopole antenna embedded with three slits in the ground plane. Its ultra-wideband (UWB) operation within the required frequency (3.1–10.6 GHz) is fine-tuned by embedding a small rectangular slit at the top center of the ground plane, whereas the band-notch function is achieved by embedding two symmetrical L-shaped slits located at both sides of the ground plane. The gain and time-domain characteristics of this antenna show that it is applicable to any wireless communication system that requires a stable signal transmission in the 5-GHz notch band excluded UWB.

A novel CPW-fed monopole UWB antenna is presented by Xin Zhang et.al. [108] to increase the impedance bandwidth, a notched ground is introduced. The optimized antenna presents 3.8:1 ratio bandwidth and 116.7% impedance bandwidth for VSWR < 2.

A novel wideband printed diversity antenna for mobile handsets is proposed and studied by Yaxing Cai et.al. [109]. The antenna consists of two monopoles with symmetric configuration. The effects of some parameters of the proposed antenna are studied. The measured relative bandwidth reaches to 29.0% (1860–2490 MHz) with acceptable isolation over the bandwidth. The measured radiation patterns of the two monopoles cover complementary space regions. The diversity
performance is approximately calculated, and the results show that the proposed antenna can provide spatial and pattern diversity.

In 2009, Sung Tae Choi et.al. [110] proposed a novel small size microstrip-fed monopole antenna with wide bandwidth and small group delay variation for ultra-wideband (UWB) applications. It consists of a triangular patch with a pair of wide stubs on the lower sides thereof and linearly tapered partial ground plane on the backside. The measured return loss of the fabricated antenna is better than -9 dB from 2.9 to 12 GHz. The radiation pattern is nearly omnidirectional, and the variation of the measured group delay between two proposed antennas is less than 1.6 ns over the entire UWB band.

An internal planar monopole antenna for use in WUSB dongle application is proposed by Youngki Lee et.al. [111]. The antenna, suitable for WUSB dongle application, occupies a compact area of 20mmx10mmx1mm. The planar antenna consists of a modified meander-strip and an inverted L-strip. The antenna elements are printed on the top and bottom sides of substrate, respectively. The impedance bandwidth of proposed antenna is enhanced by the mutual coupling between the modified meander-strip and inverted L-shape strip.

In 2009, Joong Ho Maeng et.al. [112] designed a CPW-fed planar monopole antenna suitable for ultra wideband (UWB) wireless communication. The proposed antenna has a rectangular patch with four rectangular notches and bottom elements with a CPW-fed line embedded inside the bottom elements. A HFSS (High Frequency Structure Simulator) is used to analyze the proposed antenna in the design process and to compare it with the experimental results. The bandwidth of the proposed antenna is measured as 3.083–11.000 GHz for voltage standing wave ratio 2. Measured maximum gain is 5.7 dBi at 10.00 GHz.

A simple dual-band metamaterial-inspired small monopole antenna is proposed by J. Zhu and G.V. Eleftheriades [113] in 2009 for
Wi-Fi applications. In addition to the regular monopole resonance, the metamaterial-inspired loading is exploited to create a second resonance for the lower Wi-Fi band while maintaining the antenna’s small form-factor. The measured S parameters and radiation patterns show that the proposed design is suitable for emerging WLAN applications.

Siddik Cumhur Basaran and Yunus E. Erdemli [114] proposed a novel dual-band microstrip monopole antenna based on split-ring elements is for WLAN (2.4/5 GHz) applications. The antenna fed by a two-stage microstrip line has fairly small dimensions and provides 7.5 and 25.5% impedance bandwidth performance at the respective bands. Also, the antenna exhibits almost uniform radiation patterns at each frequency band.

A novel CPW-fed antenna having a frequency band-notched function for UWB applications is proposed and studied by X. Zhang et.al [115] in 2009. By inserting a pair of inverted-T-shaped slots on the radiation element, the narrow frequency band notch has been created to cover the desired frequency varying from 3.4 to 3.69 GHz and the required UWB bandwidth is also acquainted.

Ramu Pillalamarri et.al. [116] investigated compact printed semicircular disc monopole antenna, which is basically printed microstrip antenna with etched ground plane for UWB applications. In particular they have simulated very compact semicircular disc monopole antennas for UWB communication. Simple rectangular microstrip line is used for feeding the printed monopole antenna and its frequency bandwidth under -10dB return loss is ranging from 3GHz to 11.6 GHz.

In 2009, Zissis Konstas et.al. [117] proposed a novel "green" inkjet-printed monopole antenna topology for integrated RFID-reader and cellular communication functionalities. The antenna is loaded with a parasitic strip to fulfill the design requirements for the required dual-band operation. The design characteristics of the antenna are verified for
paper-based substrates through extensive simulated parametric analysis and optimization.

The coupling between an irradiated aperture and a monopole antenna into a complex enclosure is investigated by F. Caudron et.al. [118]. The aperture is realized at the one side of the enclosure and the monopole antenna at the other side. The proposed study uses Babinet's principle to extend the Random Coupling Model to determine the radiation impedance of apertures. An experimental study is carried out using a computer box as an enclosure. A high intensity external electromagnetic radiation is applied to the aperture. The induced voltage is measured along the monopole antenna. The simulated probability levels of the induced voltages agree well with the experimental ones.

A new circularly-polarized (CP) sleeve antenna fed by a CPW for DTV signal reception applications is presented by J. C. Liu et.al. [119]. The CPW-fed sleeve monopole antenna consists of square loop sleeve, CPW-fed and complementary SIR radiators. The lower and upper resonance frequencies of the desired band are controlled by the complementary SIR arms, making designs of the wide-band antenna very easy. The CP operation for the proposed design can be achieved by properly adjusting the asymmetrical radiators. The reflection coefficient, axial ratio, radiation pattern and gain of the proposed antenna were studied, and reasonable agreement between the simulated and measured results was obtained.

In January-2010, H. Kimouche et.al. [120] studies on optimized design for a novel printed monopole antenna, with a notched semi-elliptical ground plane. A parametric study of the antenna parameters and their effects is given. The monopole antenna with the proposed bandwidth enhancement technique covers the band 3.1–10.6 GHz, which has been approved by the Federal Communications Commission as a commercial band for ultra-wideband communication systems.
A printed flame-shaped monopole antenna with a self-similar slot for wideband application has been presented and investigated by Kun Song et al. [121] in January-2010. The wideband characteristic is easily achieved by inserting a self-similar slot in the flame-shaped radiator. The effect of the slot is investigated. We discover that the slot can be effectively used for bandwidth enhancement, while the position of the slot has a negligible effect on the performance of the proposed antenna. Experimental results show that the proposed antenna obtains a bandwidth from 2.65 to over 12 GHz with VSWR<2.

A very small size planar two-strip monopole printed on a thin (0.4 mm) FR4 substrate for 2.4/5.2/5.8 GHz triple-band WLAN operation in the laptop computer is presented by Ting-Wei Kang and Kin-Lu Wong [122] in January 2010. With the aid of an embedded chip inductor of 5.6 nH in the longer strip of the printed monopole, a much reduced strip length for obtaining the resonant mode at about 2.4 GHz is obtained, thereby leading to a much reduced size of the antenna for the desired WLAN operation. When the antenna is mounted along the top edge of the display ground, it shows a height of 9 mm and a length of 6 mm only, which is about the smallest among the triple-band WLAN laptop computer antennas that have been reported.

A novel planar ultra-wideband (UWB) monopole antenna with variable frequency band-notch characteristic is proposed and investigated for UWB communication applications is by R. Movahedinia and M. N. Azarmanesh [123] in January-2010. The complementary electric-LC (CELC) resonator is etched inside the circular patch of the monopole antenna to achieve notch frequency band. The designed antenna satisfies the voltage standing wave ratio (VSWR) requirement of less than 2.0 in the frequency band between 2.8 and 12.6 GHz, while showing the WLAN band notched in the frequency band of 5–5.9 GHz.

and WLAN, IEEE 802.11 ISM band. The proposed antenna consists of a rectangular patch monopole printed antenna in which a slot is cut and dual band E shape patch is placed. The three arms in monopole antenna generates three resonate frequencies to cover 890 - 960 MHz GSM band, 1710-1880 MHz DCS band and 2.4 – 2.5 GHz ISM band. Slots are removed to coincide with central arm to obtain the second structure. Central arm of antenna resonate at GSM while the other two side arms resonate at DCS and ISM band, therefore three bands can be optimized easily.

M.S. Karoui et.al. [125] introduces the design of a wideband square and rectangular patch antennas for biotelemetry applications. These antennas are printed on a 1.6 mm thick FR4 with sizes 100*90 and 100*70 mm, respectively. A 2.1 mm wide microstrip line is used as a feed line. Both square and rectangular patch antennas exhibit a wide resonant frequency band. The square antenna operates from 1.41 to 4 GHz with a 95.8% impedance bandwidth, whereas the rectangular antenna covers the 1.56 - 3.5 GHz range with a 76.7% impedance bandwidth. These wide band properties are achieved by using an asymmetrical feed and a reduced ground plane with an appropriate gap distance.

Presentation of a compact dual band planar rectangular microstrip antenna (RMSA) for a WLAN (2.4GHz IEEE standards 802.11b/g)/WiMAX(2.6GHz IEEE standards802.16e) applications is presented by C.R. Byrareddy et.al. [126]. The two resonant modes of the presented RMSA antenna are associated with various length and width of the planar strips in which a center strip contributes for the lower resonant frequency 2.4GHz(2.26-2.4GHz with impedance bandwidth 240MHz) and two lateral strips contributes for the higher resonant frequency 2.8GHz(2.73-2.95GHz with impedance bandwidth 220MHz). The antenna is simulated using Ansoft HFSS and fabricated on an FR4 substrate with dielectric constant 4.4 and thickness 1.6mm occupies
an area of 65mm x50mm. The proposed antenna is suitable for wireless communication applications requiring a small antenna.

In S. Missaoui and M. Kaddour [127] presents the design of conformal monopole antennas on a very thin layer of flexible liquid crystals (LCs) is introduced. The flexible LC substrate can be bent and folded over the module case, resulting in a tight integration of the antenna with the frontend module. Firstly, a meander monopole antenna, designed for single band operation, is presented with details of the structure, simulation and measurement results. Secondly, a method to increase the peak gain and decrease the return loss of the antenna is proposed. The simulated results are compared with measured data, and good agreement is obtained.

P. Misra et.al. [128] describes the design of a small dual band planar antenna to operate in the ISM (2.4-2.48 GHz) and WLAN (5-6 GHz) band. Dual band operation is achieved by choosing proper microstrip radiator shape and reduced ground plane which becomes a monopole antenna.

A compact triple-band monopole antenna with two deferent slots for WLAN and WiMAX applications is proposed and experimentally studied by S. M. Zhang et.al. [129] The designed antenna obtains three frequency bands through loading an inverted E-shaped slot and an inverted C-shaped slot which incise the surface current and change the path of the current on the rectangle patch. The obtained results show that the designed antenna has impedance bandwidths of 2.4 GHz, 5.8 GHz for WLAN and 3.5 GHz for WiMAX. The return loss, radiation patterns and peak antenna gains are presented using computer simulations and measurements.

A novel multiband-printed planar monopole antenna for LTE multi-input and multi-output (MIMO) application is proposed by Yuan Yao et.al. [130]. A meandering microstrip line-loaded monopole antenna with multiband characteristic is presented. The proposed antenna
provides five frequency bands for LTE application, covering 0.7, 1.7, 2.1, 2.3, and 2.5 GHz. In order to provide low mutual coupling and envelope correlation, two of the antennas are combined with orthogonal polarizations.

P. Moeikham et.al. [131] proposes a compact ultra-wideband monopole antenna fed by CPW with a 5.5 GHz notched band of WLAN/WiMAX systems. The antenna input section is designed by using a gradual curvature central line and ground planes for ultra-wideband achievement. In order to reject the unwanted frequency of the existing WLAN/WiMAX band, the C-shaped slit with perimeter length of a half wavelength at center frequency of 5.5 GHz has been embedded into the monopole patch. The proposed antenna could potentially minimize frequency interference in the WLAN/WiMAX bands.

Rong Lin Li et.al. [132] studied on a broadband low-profile monopole antenna, and are analyzed by using balanced and unbalanced mode decomposition. The broadband antenna consists of an S-strip and a folded T-strip that are separately printed on the two sides of a thin planar substrate, forming a two-strip monopole. The two-strip antenna can achieve a bandwidth (VSWR<2) of 40% with a height of 0.08λo. It is revealed that the broadband performance of the two-strip antenna is a result of the combination of an unbalanced mode and a balanced mode. Experimental results verify the theoretical analysis.

A simple, low-cost, and surface mountable monopole antenna made of a copper wire for applications in the 2.4 and 5.2/5.8 GHz WLAN systems is presented by Fa-Shian Chang et.al. [133]. The monopole antenna occupies a compact volume of 3 × 10 × 10 mm² and generates two separate wide resonant modes for triple-band WLAN operations.

Kuldip N. Modha et.al. [134] proposed a novel Ultra Wideband (UWB) antenna. This printed planar monopole structure resembles a scoop of ice cream on a wafer cone; hence it is called as ice cream cone
antenna. This antenna has a microstrip feed and is fabricated on Rogers RT Duroid 5880 substrate. The effect of varying the antenna feed angle as well as the ground plane dimensions has been studied. The best antenna performance was obtained from the antenna with board dimensions 34mm X 17.65mm, showing a VSWR between 1 to 2 for frequencies 3.1 GHz to 5.8 GHz and in the band of 6.5 GHz to 9 GHz.

Chih-Hsien Wu et.al. [135] presented a planar T-shaped monopole antenna backed by an L-shaped ground plane and showing a wide bandwidth of larger than 250 MHz for application in a UMTS (Universal Mobile Telecommunication System, 1920 ~ 2170 MHz) mobile phone. The T-shaped monopole antenna has a simple structure, and is easy to design and fabricate. In addition, with the presence of the L-shaped ground plane, the antenna can be placed in close proximity to or in contact with the RF shielding metal case in the mobile phone, that is, no isolation distance between the antenna and the shielding metal case is required.

Nikolista Yannopoulou and Petros Zimourtopoulos [136] briefly highlights the features of the software tool [RadPat4W], named after Radiation Patterns for Windows, that is based on an alternative exposition of fundamental Antenna Theory. This stand-alone application is compatible with the [Wine] environment of Linux and is part of a freeware suite, which is under active development for many years. Nevertheless, the [RadPat4W] source code has been now released as FLOSS Free Libre Open Source Software and thus it may be freely used, copied, modified or redistributed, individually or cooperatively, by the interested user to suit her/his personal needs for reliable antenna applications, from the simplest to the more complex.

A novel internal metal-plate monopole antenna suitable for digital television (DTV) signal reception in the UHF band for laptops is presented by Chih-Ming Su et.al. [137]. This antenna is a U-shaped metal-plate monopole with a compact cross-sectional area of 5 ×10 mm². When
mounted at the top edge of the supporting metal frame of the laptop display, the proposed antenna shows a low profile of 10 mm only, yet provides a wide operating bandwidth (2.5:1 VSWR) of 310 MHz (about 50% centered at 625 MHz), making it not only suitable for DTV signal reception in the UHF band but also capable of being embedded within the casing of the laptop as an internal antenna.

Masahiro Yanagi et.al. [138] reports on the design and prototyping result of a planarized monopole antenna formed on a printed circuit board with decreased volume. In a design where the height of the monopole unit is 1/4 the wavelength of the minimum frequency or more and the shape (tear drop) and dimensions are optimized, a VSWR < 1.3 in 3 – 20 GHz was implemented.

The new antenna with microstrip ring-resonators is presented by Jin-Hyun Kim et.al. [139]. This device integrates a planar monopole antenna with microstrip ring-resonator band-stop filters. This new device is suitable for creating wideband antenna with narrowband interferer rejection characteristics.

Antennas are critical devices in the process of miniaturizing front-end RF transceiver radios system is studied by Yanyan Zhang and H. Y. David Yang [140]. They address a novel design of an ultra-small integrated wire antenna for the 2.4GHz industrial, scientific and medical (ISM) band. Based on a design of an ultra-slow wave transmission line, the proposed monopole with an area of 300mil by 166mil is 70% size reduction compared to a normal printed monopole, and has 10dB impedance bandwidth of 21.44% (550MHz) at the center frequency of 2.565GHz without additional tuning inductors.

A wideband planar monopole antenna requiring a small ground plane is described by I.L. Morrow et.al. [141]. Numerical and measured results confirms the antenna has good radiation efficiency and stable
omnidirectional radiation patterns over an impedance bandwidth of 4.1:1 covering the 200-850 MHz frequency spectrum.

Ali Ramadan et.al. [142] a small-size low-cost printed monopole antenna for ultra-wideband operation is presented. The proposed antenna, which was designed and simulated using the FEM-based HFSS, is based on a 20 mm × 40 mm × 1.6 mm. To verify its frequency response, the antenna is also simulated using CST Microwave Studio, and a prototype is fabricated and the return loss is measured. A credible analogy between computed and measured return loss data is witnessed. Furthermore, the antenna shows acceptable peak gain figures, good radiation efficiency values and omnidirectional radiation patterns over its band of operation.

Chien-Yuan Pan et.al. [143] demonstrate a new and simple multiband design of the printed monopole antenna. The antenna consists of crisscross monopole element, conductor-backed parasitic plane and microstrip feedline. The simulated impedance bandwidth for -10 dB return loss can operate from 1.91 to 2.74 GHz and 4.58 to 5.93 GHz covering UMTS, HIPERLAN and WLAN standards. The simulated radiation patterns are all very monopole-like for each operation band.

M. John and M. J. Ammann [144] describe a dual-band miniaturized printed monopole for integration in modern wireless systems. The printed monopole employs a multi-branch approach, with each branch resonating in one band. Parameter-swept investigations are shown which provide data on the optimum tap-off point and ground plane size for maximum impedance bandwidths for each band. These antennas are proposed for the emerging multi-band wireless transceivers, which operate over a wide range of bands as dictated by national authorities. Bandwidths achieved are 29% and up to 45% for the lower and upper bands respectively.
O.P. Gandhi [145] describes the concepts underlying monopole antennas and their many applications, such as for broadcasting, car radios, and more recently for cellular telephones. In its simplest form, the monopole antenna above an infinite ground plane can be considered as one-half of a corresponding double-length center-fed linear dipole.

The resonance frequency of broadband planar monopoles with different shapes is investigated by Marta Cabedo-Fabres et.al. [146]. A novel compact wide-band planar monopole antenna suitable for use in multi-service wireless devices is proposed. By adding a shorting pin to an arrow tip planar monopole, a great improvement in the bandwidth performance is achieved, while retaining good radiation characteristics.

A new tunable band-notched ultra wideband (UWB) planar monopole antenna is presented by Won-Seok Jeong et.al. [147]. The proposed antenna consists of a wideband planar monopole antenna, resonating stubs and varactor diodes. In order to generate tunable band notched characteristic, we applied quarter-wavelength stubs with varactor diode to the wideband planar monopole antenna. We interpret the mechanism for notch characteristics using surface current distributions. This new approach is suitable for designing wideband antenna with narrow band interferer rejection characteristics.

Januar Janapsatya and Karu Esselle [148] describes the design of printed slot antennas for multi-band applications. The aim of this design is to develop a single antenna that can be used by all the IEEE 802.11 WLAN network standards collectively known as Wi-Fi. It is required to have a polarization complementary to that of multi-band printed monopole antennas, to achieve polarization diversity. Design of a printed slot antenna element operating in the 2.4 and 5 GHz bands is discussed. Parametric studies are presented and different types of feedline configurations are investigated. The theoretical results are promising.
M. R. Kamarudin et al. [149] studied a switched beam disk-loaded monopole antenna array has been demonstrated that uses a coplanar waveguide (CPW) feeding technique. The antenna is designed for 2.45GHz ISM band for on-body communications or WLAN base station applications. It has a gain of 6.7dBi and the input return loss bandwidth is about 10%.

Irene Anite Jensen et al. [150] studied the CVIS (Cooperative Vehicle Infrastructure System) project is to create a wireless network between vehicle and roadside infrastructure. CVIS includes implementation of technology components, to develop a multi-channel terminal. This terminal will be installed in a vehicle, and in this paper we report on the development of the Rooftop Antenna Unit. The antenna unit contains 5 individual antennas, including two WLAN antennas. The WLAN antenna is a broadband double-fed printed monopole antenna designed and optimized within the CVIS project. It covers the frequency band 2.0-6.7 GHz, a bandwidth of 128%. The Rooftop Antenna Unit will be used for the CVIS field trials, taking place at six different test sites throughout Europe.

### 2.3 Formulation of the problem

From the above exhaustive review of the literature, it is clear that an enormous amount of work has been done on few types of monopole antennas with different feeding techniques. Each type of geometry is having its own merits and demerits in terms of antenna performance. In the review of monopole antennas, it was found that, the different shapes of planar and printed monopole antennas have been investigated by researcher for different wireless applications. Even then comparison of different shapes of slots on the planar and printed monopole antennas is not studied extensively. Many researchers have studied the performance of antennas either by embedding slots in the radiating patch or on the ground plane. But the slots on both radiating patch and ground plane are rarely found in literature. Hence a thought was given to modify the
monopole antenna geometries available in the literature by embedding slots in the radiating patch and on the ground plane.

As mentioned in the chapter 1, UWB technology has gained great popularity in research and industrial areas. UWB antennas have been investigated a lot by researchers and quite a few proposals for UWB antenna design have been reported. However, the design of those proposed papers are quite complex and size is big and difficult for mass production. Hence this has motivated us to design antenna with a very low complexity, low cost and compact size to cover the entire UWB.

Also interference is a serious problem for UWB application systems. Hence UWB with band-notch function has been designed by researchers. But the antennas with frequency band rejected function design occupy a large space of the antenna. Furthermore, some designs occupy too much wide band-notch which is more than 29GHz. However, the needed band-notches are 0.2GHz for lower WLAN band and 0.1GHz for upper WLAN band. Obtaining this band-notched characteristic is a challenging issue and we have made an effort to achieve this factor.

In view of this a systematic study of monopole antennas is carried out in following steps.

- Design and study of printed rectangular monopole antenna (PRMA) with strip-line feeding technique and truncated ground plane for broadband operation.
- Design and study of PRMA with various shapes of slots i.e., U-slot, T-slot, π-slot, J-slot, F-slot and I slots etc., is made for broadband operation.
- In the next step the combination of horizontal, U-shaped and T-shaped slots etc., for multi-frequency operations is designed and studied.
- PRMA with symmetric pair of square stubs in the ground plane and on radiating patch has been designed and studied.
• Further study is continued by making slots in the stubs, putting stubs on the sides of radiating patch.
• Design and parametric study of PRMA with L-shaped notch and truncated ground plane is made for UWB applications.
• The study of PRMA with narrow slits on radiating patch and steps in the ground plane is made for UWB applications.
• Design and study of PRMA with E-shaped notch, stub and steps on the radiating patch for UWB frequencies is carried out.
• Design and study of PRMA with T-shaped slot on the radiating patch is made.
• Design and study of PRMA with open T-shaped slot on the radiating patch is studied for UWB.
• Design of inverted T-slots in the ground plane is studied.
• Design and study of U-notches on the radiating patch.
• Design and study of double C-slots in the ground plane for UWB operation.
• Design and study of wide rectangular slot on the radiating patch is made.
• Also, the PRMA with band notch function is designed and studied.

The above extensive study has been made in a systematic way by designing and simulating the various monopole antennas with different slots using Mentor Graphic’s IE3D simulation software and then fabricated to carry out the experiments using Vector Network Analyzer. The methodology and experimental setup is discussed in detail in the next chapter.