CHAPTER II

2.1 LITERATURE REVIEW

‘Everybody wants to go wireless’ and this describes the trend in modern wireless communications. At the end of the nineteenth century, James Clark Maxwell, who was a Scottish scientist in the field of mathematical physics, laid the initial foundation for electromagnetic radiation [1]. The Maxwell’s theory was supported by the experiments that were conducted by Heinrich Hertz. He proved that light and electromagnetic waves both travel with the same velocity. Heinrich Hertz’s experiments about electromagnetic waves have led to the development of modern day’s technology like wireless telegraphy and radio [2].

In 1901, Guglielmo Marconi transmitted the letter ‘S’ by using three dots in Morse code over a distance of 1.8 miles [3]. With the effort of these scientists, the users obtained a stronger freedom to communicate. This initial success in wireless communications began as a reality, and further exploration was made towards the booming area of the modern personal communication systems.

They act as interfaces between the circuitry and the free space. The IEEE standard defines that an antenna as a means for "Transmitting and receiving electromagnetic waves" [5]. If there is no antenna, literally there are no communication devices. The works by Hertz and Bose have inspired Guglielmo Marconi; Marconi was an Italian Electrical Engineer who used the Hertzian waves for communication.

Marconi started a scientific community in the year 1901 through his transatlantic radio communication link; this transatlantic radio communication link had been headed into space and it got reflected in the ionosphere and it then bounced back to Canada. This setup consists of a spark transmitting antenna, which connects the ground and a system having 50 vertical wires. This antenna can transmit or receive electromagnetic waves, so there is information exchange between various locations without any intervening structures.

Considering microwave frequencies, the dimensions are so important, so the realization of microstrip antennas requires more than that of low-frequency printed antennas. A wide variety of these substrates with dielectric constants ranging from 2 to
around 25 in the entire microwave frequency with very good mechanical flexibility are available [6].

Flexible electronic devices give controlled and smooth functional layers, but they require a dust-free, controlled temperature environment, which are expensive to build, maintain and operate (7).

Along with the advantages of low cost, printing also offers a wide variety of flexible and rigid substrates. However, there are lots of challenges in the printing of functional electronic devices such as smoothness, print quality and accuracy requirements. Substrate properties such as smoothness, compressibility, porosity, wettability and ink receptivity, etc. and ink properties like ink chemistry, drying viscosity, solvent evaporation rate, etc. are therefore crucial. (8).

Printed Electronics (PE) is not new for quite some time, since early it has received a lot of attention due to the ability to print low cost flexible electronics through the roll-to-roll additive manufacturing method. Flexible displays, smart packaging, smart textiles and photovoltaic cells are manufactured like this (9).

Wideband antenna concepts had been reported in 1947 [11] by the United States Radio Research Laboratory (RRL) of Harvard University. They have developed lot of concepts related to antennas like sleeve antennas, inverted trapezoidal antennas, etc.

In 1950, the concept of spiral antennas was introduced as frequency-independent antennas. Spiral antennas provide circular polarization in low-profile geometry [12].

In 1982, R.H. Duhamel had invented a new antenna called sinuous antenna, which provided dual linear polarization with a wide bandwidth in compact, low-profile geometry [13].

This antenna is much more complicated than the spiral antenna. It actually provides dual orthogonal linear polarization, so it can be definitely used for polarization diversity [14].

Normally, the portable wireless devices are small in size the antenna's size that is used should also be very small, then only the antenna can be embedded into the devices. [15].

Material sputtering was initially reported in 1852 by Sir William Robert Grove [21], and it was considered to be an unwanted dirt effect. Sputtering is generally a momentum and energy transfer process between the incident particle and the target atoms. The sputter yield differs for different target materials. Sputtering was used by
the industry almost a century later due to substantial improvements of the vacuum equipment and an increased demand for high quality thin films [18].

The science of plasma underlies a lot of important technological applications. They also provide the base for the present day applications like plasma processing of semiconductors, sterilization of medical products, etc. [25].

Plasma science provides the foundation for the generation of electrical energy from fusion [26]. It is believed that plasma constitutes around 99% of the visible universe like the sun, the stars, etc.

Plasma science includes plasma physics and aspects of chemistry. Plasma physics components include ionized gas. Plasma ranges from relatively high-pressure gas to very low-density gases where the fraction of gas atoms ionized is very high. The fusion plasmas are generally considered as the energy source for future [27].

Plasma is characterized by several properties such as the degree of ionization, the temperature of the electrons, etc. The plasma analysis is essential for the plasma-assisted thin film deposition. Plasma affects properties like ionization, incident energy, direction, etc. which in turn affects the characteristics of the film strongly [29, 30].

Organic substrates offer the unique advantage of being much cheaper, lighter and more eco-friendly in processing and also in the disposal of antennas than current substrates like FR4. They have the additional advantage of providing flexibility too. Flexible devices can be quickly fabricated. Eco-friendly and disposable antennas can be fabricated by this technology. The first published paper on printed monopole antennas started to appear in the literatures of the year 2007 for the RFID integration of low cost flexible substrates to target the inventory control and supply chain management markets [31].

The cellulosic paper used for monopole antennas can potentially revolutionize the electronics market. It could eventually take the first step in creating eco-friendly RF electronics and modules. In addition, cellulosic paper is one of the lowest cost materials that have been produced [32].

The antennas thus developed have the advantages of small size, low profile and simple configurations. The low profile of the antennas makes it promising for slim and compact wireless devices [33].
Sangkil Kim et al. (2012) designed a micro strip antenna for wearable applications which has better antenna gain and maintains a low profile. It has a bandwidth of -10 dB, which covers the entire frequency range of IEEE 802.15 standard, which is a very good application for wearable electronic devices [34].

The feasibility of realizing the ultra wideband antennas through ink jetting of conductive inks on commercially available paper sheets is reported for frequencies up to 10 GHz and above that as well [35].

The development of compact five band printed antenna for fixed or reconfigurable communication systems was designed by using four varactors. This design enables the four bands to be tuned independently over wide frequency ranges [36].

Zhongkun Ma and Guy A. E Vandenbosch (2013) designed an antenna of operational frequency band that targeted neglecting the oxidation effects. In that, metallic silver was the best choice for communication signals having a wavelength of above 500 nm, and aluminum was the best choice for wavelengths of below 500 nm. Due to the oxidation effects of this metal, the threshold shifts to a wavelength of about 700 nm [37].

The effects on the dispersive properties of some important metals were studied, and the input impedance of Ag > Al was observed [38].

The excellent conductive values of metallic silver was attained by using a very small amount of organic additives without any strong adsorbing groups such as amides and amines. Even at low temperatures, the conductivity of the printed antennas by using nanonmaterials was highly dependent on the organic additives used. This low sintering temperature enhances the conductivity of the flexible materials [39].

The advantages of designing a low-profile antenna on a high impedance surface offer a viable solution for naval, vehicle and aerospace platforms [40].

The planar modified dipole antennas have an enhanced radiation performance in terms of maximum gain and stability. Moreover, this type of antenna has much wider impedance bandwidth characteristics [41].

In modern multipurpose handheld gadgets, different communication technologies are embedded in the same device which shares the same antenna. Nowadays, there is a great demand for wide band antennas that are small in size having low-profile, light weight, low cost and easy to fabricate and install [42].
These paper-based RFID tag antennas are fabricated by using the commercially available ink-jet printers by using nanosilver ink. The performance is improved by modifying the ink's properties [43].

The planar dipole antenna with a flat reflector and the nonplanar antenna have a good balance between the impedance bandwidth and pattern bandwidth. Thus, the operating bandwidth was improved significantly. The combination of nonplanar dipoles and nonplanar reflectors is very attractive for a larger operating bandwidth [44].

The compact, omnidirectional printed quasi-Yagi antenna decreases the antenna size, and its radiating elements operate at 915 MHz. The new ATL (Artificial Transmission Line) structures have compact arms of a quasi-Yagi antenna for RFID applications. The presence of this ATL structure results in the reduction of the quasi-Yagi antenna arm's length from 0.25 \( \lambda \) to 0.1 \( \lambda \) [45].

The new broadband antenna inherits a wide bandwidth with its height that is considerably reduced from \( \lambda \) to 0.03 \( \lambda \) of its lowest operating frequency. This new design consists of a top loaded monopole antenna with several shorting pins and inductive loading [46].

A high gain, low-profile miniaturized antenna with omnidirectional and vertically polarized radiation is presented in [47]. The gain and polarization improvement are achieved by isolating the feed structure from the miniaturized resonant radiating structure by using inductive and capacitive couplings.

Printing additional layers on critical areas was shown to be effective, in terms of attenuation loss and the total efficiency of the antennas. The result of two printed layers was achieved by the printing of the second layer only on high current-density areas. For printing, the process was adapted optimally for multiple layers with minimum ink in the first layer. The decrease in attenuation was seen to be limited that shows a promising option for decreasing loss, without increasing the usage of ink [48].

This printed monopole antenna for ultra-wideband applications with a frequency band-notch characteristic is presented. The proposed antenna consists of a stepped rectangular radiating patch and modified ground plane that provides a wide usable fractional bandwidth of more than 120% [49].

The circularly polarized printed antenna, capable of operating over and octave bandwidth is designed and fabricated. The design has evolved from a classical printed
monopole. This antenna employs a microstrip-line fed rectangular radiator, printed on the top of the substrate [50].

The demonstrated UWB monopole antenna with a fractal matching network is the smallest reported antenna with operation over the entire UWB band, which is important in the realization of low-cost, high data rate wireless sensor networks and wearable wireless devices [51].

The design and development of a small antenna gathered significant interest due to the development of mobile devices and the attention for small antennas is rapidly growing because of the rapid growth of mobile communication devices [52]-[55].

Some of the important considerations for developing small antennas are that they should be less weight, compact, low profile and have very good flexibility. [56].

Mobile handsets are required to operate at multiple standards and operate at a wide spectrum and also, provide multiband operations [57].

Patch antennas are commonly excited by one of the five methods: (a) Coaxial probe, (b) Micro line feed connected to the edge of the patch, (c) microstrip line coupled to the patch through the electromagnetic method, and (d) microstrip line coupled to the patch through aperture and (e) Co-planar feed. [58]-[61]. The selection of an appropriate feed depends on the application.

In the mid 1960's, Professor Harrington worked out a systematic, functional space description of electromagnetic interactions, which he called the 'Method of Moments' (MoM). The MoM is a general method for solving linear operator equations [65]. Here, an integral or integro-differential equation derived from Maxwell's equations for the structure of interest is interpreted as the infinite dimensional functional equation. The MoM approach is to set up a numerical solution by representing the unknown function f as a linear combination of a finite set of basis functions $f_i$ in the domain of L. This set of equations is then solved to obtain the approximate or exact solution of f, depending on the choice of the basis and weighting functions. The set of basis functions should have the ability to accurately represent and resemble the anticipated unknown function, while minimizing the computational effort required [62].

In principle, the MoM can be applied to the numerical modelling of arbitrary linear structures. However, this method has limitations primarily governed by the speed and storage capabilities of available digital computers [63].
Using more powerful computers increases the capability of the MoM. Another option is to refine the method by choosing proper starting equations, developing flexible basis and weighting functions and using more sophisticated algorithms for the numerical evaluation of integrals encountered in the solution.

However, MoM techniques based on integral equations are not very effective when applied to arbitrary configurations with complex geometries or inhomogeneous dielectrics. Nevertheless, they do an excellent job of analyzing a wide variety of 3-dimensional electromagnetic radiation problems. Historically, the use of basis and testing functions to discrete integral equations of electromagnetics is most often named the ‘Method of Moments’, the same process applied to differential equations is usually known as the ‘finite element method’. However, the term finite element method is reserved for variation methods, explicitly minimizing a quadratic function [64].

An inverted-‘F’ antenna is designed and can be matched to 50 Ω without the need for any external matching, the addition of two side elements that are having resonance frequencies close to the main resonance extends the bandwidth [66], [67].

Inverted-F antennas (IFAs) can be used in mobile communication because of the design flexibility and often can be utilized in mobile communications, and moreover it is low-profile [68] – [70].

Multiband low-profile antennas are used for diverse applications like military and commercial. In high frequency and very high frequency bands, the antennas often resemble the whip, which is having a height of around 1 to 2 meters [71] – [74].

Consider the printed inverted F antenna (PIFA) operating in the GSM frequency range of around 800 or 900 MHz, where the ground plane has been used as a radiating part. The user’s hand degrades the performance of the radiating part, if it is fitted in a mobile phone [75] – [78].

Wireless gadgets are constantly getting smaller. The latest trend in terminal design is therefore ultra thin phones, leading to very small heights above ground plane available to the antenna elements. This has a huge impact on patch type of antennas such as the popular Planar Inverted F Antenna (PIFA) as the achievable bandwidth and radiation efficiency is proportional to its height [79].

The inverted-F antenna printed on a dielectric substrate and the printed metallic strip of the antenna is shorted to the ground plane on the other side of the dielectric
substrate for an application in wireless communication which has been demonstrated [80-81].

PIFA can resonate at a smaller antenna size as compared to conventional antennas. For both designs, an integrated inverted-F antenna for blue-tooth applications and a coplanar wave guide-fed folded inverted-F antenna for application to the UMTS band is available. To achieve dual-band operations for the WLAN and HIPERLAN systems, printed monopoles in the form of an F-shaped structure have also been tried [82-83].

The PIFA designs usually occupy a compact volume and can be integrated within the mobile housing, leading to the internal mobile phone antenna. These internal antennas can avoid the damages such as breaking compared with the conventional protruded whip or monopole antennas used for handheld applications.

Compared to the whip antennas, the PIFA’s have the advantage of relatively smaller backward radiation towards the mobile phone user. This suggests that electromagnetic energy absorption by the user's head can be reduced. These advantages led to many novel PIFA designs, most of them capable of dual or multiband operation to be applied in the mobile phones in the market. A variety of designs for dual-band PIFA used in mobile handsets can be found in the literature [84-88].

The size of the antenna is a very important parameter because of the behaviour that the antenna depends upon the dimensions in terms of free space wavelength (\(\lambda\)). The antenna is considerably smaller and the dimension is less than twice the radius of the radian sphere; so its radius is \(\lambda/2\pi\) [89].

Another versatile antenna which has large attention recently is the printed monopole antenna. They offer large bandwidth and are more attractive for wireless communication applications. The large ground plane used for the conventional printed monopole is the main limitation. However, the move towards the truncated ground plane has made the antenna low profile and suitable for integration into a circuit board [79].

Recently, printed antennas have received much attention due to their low profile and omnidirectional radiation characteristics. The rapid growth of Ultra Wide Band communication is due to the printed antenna[81].

Compared with traditional wire antennas, printed dipole antennas have extra advantages, including planar structure, small volume, light weight and low cost, which
are significantly suitable for applications sensitive to the receiver sizes. Recently, various types of printed dipole antennas have been studied [90-92].

The diversity of applications and operational environments have led through the accompanying high production volumes to tremendous advances in cost-efficient manufacturing capabilities of microwave and RF products. This, in turn, has lowered the implementation cost of a host of new wireless as well as wired RF and microwave services. Inexpensive handheld GPS, navigational aids, automotive collision-avoidance radar and widely available broadband and digital service access are among them. Microwave technology is naturally suited for these emerging applications in communications and sensing[93].

This antenna is having a simple structure, yet it has high gain and wide bandwidth, and is constructed by using a single layer printed-circuit-board (PCB)[94].

A novel polarization-reconfigurable mechanism based on a polarization-rotation artificial magnetic conductor structure is given, in which three polarization states of right-handed, left-handed circular polarization (RHCP, LHCP) and +45° linear polarization (LP) is realized by controlling the DC bias of the switches.[95]

Table 2.1. Comparison of Concepts and Issues

<table>
<thead>
<tr>
<th>Concepts and methods used</th>
<th>Issues</th>
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</thead>
<tbody>
<tr>
<td>Low-profile inverted-F antenna with parasitic elements on an infinite ground plane that is developed by H. Nakano, R. Suzuki, and J. Yamauchi,</td>
<td>FR4 is used, which is not biodegradable</td>
</tr>
<tr>
<td>Realization of dual frequency and wide-band VSWR performances using inverted-F antennas by H. Nakano, N. Ikeda, Y. Wu, and R. Suzuki,</td>
<td>FR4 is used, which is not biodegradable</td>
</tr>
<tr>
<td>Dual-frequency planar inverted-F antenna that is developed by Z.D. Liu, P.S. Hall, and D. Wake,</td>
<td>The antenna that is developed is not made of an eco-friendly material</td>
</tr>
<tr>
<td>The compact Planar Inverted-F Antenna for dual frequency operation in 900 and 1800-MHz developed by C.R. Rowell and R.D. Murch,</td>
<td>The antenna that is developed is not made of an eco-friendly material</td>
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<tr>
<td>Description</td>
<td>Details</td>
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<tr>
<td>New slot configurations for dual-band planar inverted-F antenna that is</td>
<td>FR4 is used, which is not biodegradable</td>
</tr>
<tr>
<td>developed by P. Salonen, M. Keskilammi, and M. Kivikoski,</td>
<td></td>
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<tr>
<td>Systematic Full-Wave Characterization Of Real-Metal Nano Dipole Antennas</td>
<td>Here aluminum is used, due to oxidation only frequencies below 700 MHz</td>
</tr>
<tr>
<td>developed by Zhongkun Ma And Guy A. E. Vandenbosch</td>
<td>can be used</td>
</tr>
<tr>
<td>Sputter-Deposited Thin Films Planar Inverted-F Antenna developed by</td>
<td>This antenna is having a peak efficiency of only 18%. Efficiency can be</td>
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<tr>
<td>Book-Sung Park, Jee-Myun Lee, Seon-GU Lee, Min-Seok Kang, and Jin-IL Choi,</td>
<td>increased</td>
</tr>
<tr>
<td>Low Profile Fully Planar Folded Dipole Antenna On A High Impedance Surface</td>
<td>The antenna that is developed is not made of an eco-friendly material</td>
</tr>
<tr>
<td>developed by Andrea Vallecchi, Javier R. De Luis, Filippo Capolino And</td>
<td></td>
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<tr>
<td>Franco De Flaviis,</td>
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<tr>
<td>Multiband And Wideband Properties Of Printed Fractal Branched Antennas</td>
<td>The antenna is not flexible</td>
</tr>
<tr>
<td>developed by M. Sindou, G. Ablart, and C. Sourdois,</td>
<td></td>
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From the Table 2.1, it is very clear that most of the antennas are using highly toxic materials like FR4, which are not biodegradable. Other antennas are not using flexible substrates, so such antennas cannot be used for foldable applications.