Chapter 2

METHODOLOGY AND ANTENNA REVIEW

2.1 Fabrication of the proposed antenna
2.2 Antenna measurement facilities
2.3 Measurement procedure
2.4 Planar Near field measurement set up
2.5 Cavity perturbation method for dielectric constant measurement of phantom equivalent liquid
2.6 Electromagnetic simulation tools
2.7 Planar antennas-Review
2.8 Mobile antenna with reduced user interference –review
2.9 Chapter conclusion

This chapter describes the experimental and simulation facilities utilized to characterise the behavior of a mobile antenna in the near and far field were presented. The proposed antennas were fabricated using the photolithographic facility. The antenna characteristics such as return loss, radiation pattern and gain measurements were carried out at our test facility consisting of vector network analyzer and anechoic chamber. The Finite Element Method (FEM) based Ansoft High Frequency Structure Simulator (HFSS) and SAM head model provided by CST microwave studio were employed, for simulation studies and SAR estimation. A PIC based probe mounted scanner is used for near field study. A concise description of the measurement techniques employed to analyze the experimental results are also included. The chapter concludes with the literature survey of Coplanar Waveguide fed antennas and mobile antennas with reduced user interference.
2.1 Fabrication of the proposed antenna

Proper selection of substrate material is the essential part for the design of planar antennas. As frequency of operation increases, the loss tangent of the material used for substrates slightly increases, which in turn adversely affect the efficiency of the antenna. The power handling capability of the antenna also depends on the substrate materials also. A variety of substrate materials are available in the market. Polytetrafluroethylene (PTFE), polystyrene, polyolefin, polyphenylene, alumina, sapphire, quartz, ferromagnetic, rutile and semiconductor substrates permit considerable flexibility in the choice of substrates. For the antenna design at the microwave frequencies substrates such as PTFE and quartz can be preferred for good radiation efficiency. These offer excellent electrical performance, but the substrate costs are often too high. Flexible substrate materials are also available, so that the antenna can be mounted on curved surfaces. The selection of dielectric constant of the substrate depends on the application of the antenna and the radiation characteristics specifications. It is worth noting that high dielectric constant substrates cause surface wave excitation and low bandwidth performance. This will generate spurious radiations in unwanted directions from the antenna. The low cost and easily available substrate material like FR4 epoxy substrate can also be used for initial studies.

After the proper selection of the substrate material, a computer aided design of the geometry is made and a negative mask of the geometry to be generated is printed on a butter paper. The double side copper cladded substrate of suitable dimension is properly cleaned using acetone and dried in order to avoid discontinuities caused by the impurities. Any disparity in the etched structure will shift the resonant frequency from the predicted values, especially when the operating frequency is very high. One side of the substrate is made liquid proof by covering it with plastic sealing tape. A thin layer of negative
photo resist material is applied on the opposite side using spinning technique and is allowed to dry.

The negative mask is placed just above it without any air layer and exposed to ultra violet radiation. The layer of photo-resist material in the exposed portions hardens. Now the board is immersed in developer solution for few minutes. The hardened portions will not be washed out by the developer solution. The board is then dipped in the dye solution in order to clearly view the hardened photo resist portions on the copper coating. After the developing phase the unwanted copper portions are etched off using Ferric Chloride (FeCl₃) solution to get the required antenna geometry on the substrate. The etched board is rinsed in running water to remove any remaining etchant. FeCl₃ dissolves the copper parts except underneath the hardened photo resist layer after few minutes. The laminate is then cleaned carefully to remove the hardened photo resist using acetone solution. The same procedure and steps were repeated on the other side of the substrate. The various steps involved in the fabrication process are illustrated in figure 2.1. The SMA connector is carefully soldered to the structure at the precise position.

![Various steps involved in the fabrication process](image)

**Fig. 2.1. Various steps involved in the fabrication process**
2.2 Antenna measurement facilities

A brief description of equipments and facilities used for the measurements of antenna characteristics is presented in this section. Antenna radiation characteristics such as return loss, radiation pattern and gain are measured using HP8510C Vector Network Analyser and associated setup. The indigenously developed CREMA SOFT is used for the automatic measurement and data acquisition using HP 8510C Network analyzer. The important systems used for the antenna characterization are Vector network Analyzer, Anechoic Chamber, Automated turn table etc.

2.2.1 HP 8510C Vector Network analyzer (VNA)

This is a sophisticated Vector Network Analyzer (VNA) from Hewlett Packard with time domain operation capability [1]. The 32 bit microcontroller MC68000 based system can measure the magnitude and phase of the two port network parameters such as $s_{11}$, $s_{12}$, $s_{21}$ and $s_{22}$ very accurately. The inbuilt signal processing algorithms of the network analyzer processes the transmit and receive data and displays the results in many plot formats. The network analyzer consists of microwave source, S parameter test set, signal processor and display unit. The synthesized sweep generator HP 83651B uses an open loop YIG tuned element to generate the RF stimulus. It can synthesize frequencies from 10 MHz to 50 GHz. The frequencies can be set in step mode or ramp mode depending on the required measurement accuracy. The antenna under test (AUT) is connected to the two port S parameter test set unit, HP8514B. The forward and the reflected wave at the port are then down converted to an intermediate frequency of 20MHz and fed to the detector. These signals are suitably processed to display the magnitude and phase information in the required format. The constituent modules are interconnected.
using HPIB system bus. An in-house developed MATLAB based data acquisition system coordinates the measurements and saves the data in the text format.

2.2.2 Agilent E8362B PNA

The Agilent E8362B is a member of the PNA series network analyzer platform and provides the combination of speed and precision for the demanding needs of today's high frequency, high performance component test requirements. The PNA Series meets these testing challenges by providing the right combination of fast sweep speeds, wide dynamic range, low trace noise and flexible connectivity. The operating frequency of the system is from 10 MHz to 20 GHz. It has 16,001 points per channel with < 26 µsec/point measurement speed. This analyzer is used for the reflection coefficient studies. The measurement setup and the specifications of the PNA are depicted in figure 2.2 and table2.1 respectively.

Fig. 2.2. Measurement setup and PNA Specifications
Table 2.1. Specifications of PNA

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operating Band</td>
<td>10MHz to 20 GHz</td>
</tr>
<tr>
<td>IF Bandwidth</td>
<td>1Hz to 40KHz</td>
</tr>
<tr>
<td>RF Connector</td>
<td>3.5mm, 50 Ω</td>
</tr>
<tr>
<td>CPU</td>
<td>Intel Pentium 1.1 GHz</td>
</tr>
<tr>
<td>I/O ports</td>
<td>USB, LAN, GPIB</td>
</tr>
<tr>
<td>O/S</td>
<td>Windows XP</td>
</tr>
<tr>
<td>Measurement Automation Software</td>
<td>CREMA Soft</td>
</tr>
</tbody>
</table>

2.2.3 Anechoic chamber

The anechoic chamber provides a ‘quite zone’, free from all types of EM distortions. All the antenna characterizations were done in an Anechoic chamber to avoid reflections from nearby objects. The room consists of microwave absorbers [2] fixed on the walls, roof and the floor to avoid the EM reflections. A photograph of the anechoic chamber used for the study is shown in Fig. 2.3 below.

Fig. 2.3. Photograph of the anechoic chamber used for the antenna measurements
High quality low foam impregnated with dielectrically / magnetically lossy medium is used to make the microwave absorber. The tapered shapes of the absorber provide good impedance matching for the microwave power impinges upon it. Aluminium sheets are used to shield the chamber to avoid electromagnetic interference from surroundings.

2.2.4 Automated turntable assembly for far field measurement

The turn table assembly kept at distance greater than $\frac{2D^2}{\lambda}$ consists of a stepper motor driven rotating platform for mounting the Antenna Under Test (AUT). An indigenously developed microcontroller based antenna positioner STIC 310C is used for radiation pattern measurement. The AUT is used as the receiver and a standard wideband ridged horn (1-18GHz) is used as transmitting antenna for radiation pattern measurements. The main lobe tracking for gain measurement and radiation pattern measurement is done using this setup. Antenna positioner is interfaced to the computer and with the in-house developed software ‘Crema Soft’ will co-ordinate the automatic measurements.

2.2.5 Crema Soft: Automated antenna measurement

The user friendly software CremaSoft is built in MATLAB™ environment. The powerful instrument control toolbox of the package is used for communicating with the stepper motor control and Network Analyzer using RS232C and GPIB interfaces. This automated software can be used for calibration, antenna measurements and material characterization of the substrate used for the antenna.

2.3 Measurement procedure

The experimental procedures followed to determine the antenna characteristics are discussed in the following sections. Power is fed to the antenna from the
network analyzer through different cables and connectors. The connectors and cables will have its losses associated at higher microwave bands. Hence the instrument should be calibrated with known standards of open, short and matched loads to get accurate scattering parameters. There are many calibration procedures available in the network analyzer. Single port, full two port and TRL calibration methods are usually used. The two port passive or active device scattering parameters can be accurately measured using TRL calibration method. Return loss, VSWR and input impedance can be characterized using single port calibration method.

### 2.3.1 Reflection coefficient, Resonant frequency and Bandwidth

The reflection coefficient \( \Gamma \) at the antenna input is the ratio of the reflected voltage (current) to the incident voltage (current) and is same as the \( S_{11} \) when the antenna is connected at the port 1 of the network analyzer. It is a measure of the impedance mismatch between the antenna and the source line. The degree of mismatch is usually described in terms of input VSWR or the return loss. The return loss (RL) is the ratio of the reflected power to the incident power, expressed in dB as

\[
RL = -20 \log (|\Gamma|) = -20 \log (|S_{11}|)
\]

The return loss characteristic of the antenna is obtained by connecting the antenna to any one of the network analyzer port and operating the VNA in \( S_{11}/S_{22} \) mode. The calibration of the port is done for the frequency range of interest using the standard open, short and matched load. The calibrated instrument including the port cable is now connected to the device under test. The frequency vs reflection parameter \( S_{11}/S_{22} \) values is then stored on a computer using the ‘Crema Soft’ automation software.
The frequency for which the reflection coefficient value is minimum is taken as resonant frequency of the antenna. The range of frequencies for which the reflection coefficient value is within the -10dB points is usually treated as the bandwidth of the antenna. The antenna bandwidth is usually expressed as percentage of bandwidth, which is defined as

\[
\text{%Bandwidth} = \frac{\text{bandwidth}}{\text{centre frequency}} \times 100
\]

The voltage standing wave ratio (VSWR) is the ratio of the voltage maximum to minimum of the standing wave existing on the antenna input terminals. A well-matched condition will have return loss of 15dB or more. A VSWR equal to 2 gives a return loss of \(\approx 10\text{dB}\) and it is set as the reasonable limits for a matched antenna.

### 2.3.2 Far field radiation Pattern

The measurement set up for radiation pattern is illustrated in figure 2.4. The radiation pattern of an antenna is graphical representation of its radiation properties as a function of the space coordinates. This is usually a three dimensional (3-D) pattern. Because of the practical limitation of the 3D measurement setup, usually patterns are measured in the two principal coordinate planes (YZ and XZ) for antennas fabricated on the XY plane. The far field patterns are measured at a distance \(d > \frac{2D^2}{\lambda}\), where \(D\) is the largest dimension of the antenna and \(\lambda\) is the smallest operating wavelength, to ensure far field criteria.
The measurement of far field radiation pattern is conducted in an anechoic chamber with the time gating facility of Vector Network Analyzer HP8510C to ensure a reflection free environment. The AUT is placed in the quite zone of the chamber on a turn table and connected to one port of the network analyzer. A wideband horn is used as a transmitter and connected to the other port of the network analyzer. The turn table is controlled by STIC positional controller. The automated radiation pattern measurement process is coordinated by the ‘Crema Soft’ software in the computer, interfaced with the network analyzer and the positional controller.
In order to measure the radiation pattern, the network analyzer is kept in $S_{21}/S_{12}$ mode with the frequency range within the -10dB return loss bandwidth of the antenna under test. The number of frequency points is set according to the convenience. The start angle, stop angle and step angle of the motor is also configured in the ‘Crema Soft’. The antenna positioner is bore sighted and a THRU calibration is performed for the frequency band of interest. This is saved in the CAL set of the network analyzer. Suitable gate parameters are provided in the time domain to avoid spurious radiations if any. The Crema Soft will automatically perform the radiation pattern measurement and store it as a text file.

2.3.3 Antenna Gain

The gain of the antenna under test is measured in the bore sight direction. The gain transfer method using a standard gain antenna is employed to determine the absolute gain of the AUT [3-4]. This method uses a standard wide band ridged horn antenna and the AUT. The standard horn antenna whose gain chart is available is chosen as the reference antenna ($G_{\text{ref}}$ (dBi)). The reference antenna is placed in the antenna positioner and THRU calibration is done for the frequency range of interest. Standard antenna is then replaced by the AUT and the transmission coefficient $S_{21}$ (dB) is recorded. Gain measurement set up is shown in figure 2.5. Note that the AUT should be aligned for maximum received power so that the gain in the main beam direction is measured. This is the relative gain of the antenna with respect to the reference antenna. The absolute gain of the antenna is obtained by adding this relative gain to the original gain of the standard antenna.
2.4 Planar Near field measurement set up

The near field characteristic of the antenna in the presence of phantom fluid is measured using the indigenously developed measurement setup and the supporting software developed by CREMA. The aim is to measure the E-field distribution in a volume of biological phantoms, filled with a tissue equivalent fluid. The designed antenna is placed near the phantom and the field probes are inserted into the phantom fluid. The transmitted power deposition was measured using a short E field probe antenna. The electric field at various locations within the phantom are sampled using the probe. The sum of the squared magnitudes of all the three components of electric field in each location will provide the power at that location in the phantom.

2.4.1 Block diagram

The block diagram of the system, developed is shown in figure 2.6 and the photograph of the experimental setup is shown in figure 2.7.
Fig 2.6. The block diagram of the measurement system

The system comprises of the following parts.

1) Phantom head model
2) Head simulating fluid
3) E field probe
4) X-Y Scanning system
5) X-Y Controller
6) HPIB Interface and Network Analyser
7) Software for automation

2.4.2 Block diagram details

24.2.1 Phantom Head model and Head simulating liquid

The semi cylindrical phantom head model is fabricated with low loss plaster of Paris material. The phantom is filled with a saline/sucrose solution, mixed in proportions based on standard recipe [5]. The prepared phantom equivalent liquid is measured for its dielectric constant and compared with the dielectric constant of the head. The dielectric constant of the material was
measured using cavity perturbation technique to ensure its suitability as a brain simulation liquid.

Since recipes for ingredients do not produce exactly correct values, partly because of inaccuracies in mixing and partly because of variations in the properties of ingredient, the measured value is slightly different from the standard specifications. However, this liquid will provide nearly brain like medium for EM waves and can be used to provide a qualitative idea of specific absorption rate in head tissue.

The microwave antenna under test is mounted very close to the phantom head model by using a RG/178BU flexible coaxial cable. To evaluate the performance of the antenna experimentally, the antenna is placed very close to the surface of a cylindrical phantom filled with a phantom equivalent material.

24.2.2 The Electric probe (E field probe)

The Electric probe (E field probe) to detect the electric field is fabricated by removing the outer conductor and Teflon dielectric of a long semi rigid coaxial cable. The length of the stripped section is 3mm. The E field probe tip is inserted into the phantom fluid. The position of the E probe and antenna is adjusted such that XY scanner can scan 5cm X 5cm area in XY plane with 0.25mm resolution. After each scan in XY plane, the probe is moved in the Z direction by 0.25mm and the process is repeated. Thus scanning in the Z plane is also carried out for 5cm, to have an effective measurement in a cube of dimension 5cm³.

The measured electric field in three orthogonal polarizations allows the reconstruction of the electric field in the phantom from which the relative SAR
can be deduced. The measurement is repeated for various fabricated antenna structures and their characteristics are analyzed.

24.2.3 X-Y Scanning system and X-Y Controller

A Microcontroller (PIC16F73) based stepper motor controller is used to move E field probe inside the phantom fluid at different positions. This is interfaced with the X-Y Scanning system. The above system is interfaced with HP8510C Network Analyser using HPIB interface.

24.2.4 Interfacing with Network Analyser and Software for automation

A user friendly software, for automatic SAR measurement developed in MATLAB by CREMA, CUSAT is used for data acquisition and measurement.

The GUI developed (measurement window) for the measurement is shown in figure 2.8.
Fig 2.8. Measurement window for SAR estimation

The electric field at the required position can be directly computed by measuring the transmission coefficient parameter ($S_{21}$) of the antenna. The antenna under test and the E-field probe are properly positioned at the desired position from where the scanning is to be started. The scanning area can be either above or below the original position of the E-field probe. The required scanning volume of the measurement system can be suitably selected by choosing the X, Y and Z dimensions. Options are given to scan either top or bottom of the original position. The movement of the E field probe is controlled by a stepper motor controller. The stepper motor controlled by a controller (PIC 16F77A) is interfaced with the PC using a MATLAB program. The start frequency, the stop frequency and number of data points can be selected from the software. The conductivity and density of the phantom fluid can also be specified in the GUI. SAR can be estimated either over 1g or 10g of the tissue. The measure button starts the measurement over the required volume.
2.5 Cavity perturbation method for dielectric constant measurement of phantom equivalent liquid

Perturbation method otherwise known as cavity perturbation method [6] based on perturbation theory is simple and accurate method to solve many of the electromagnetic field problems. The cavity perturbation technique is widely used for the determination of the dielectric characteristics of samples having low and medium dielectric loss. The material under test is taken in a capillary tube and inserted into the rectangular waveguide cavity resonator where the maximum perturbation occurs. The real and imaginary parts of the permittivity can then be calculated from the shift in the resonance frequency and Q measurements.

A rectangular X band waveguide cavity of nearly 100 mm length is used for the measurement. The cross-section dimensions are 22 mm in width and 10 mm in height. Two thin conducting sheets with optimum iris are used to form the cavity and to close the two ends of the waveguide. Figure 2.9 shows the waveguide resonator and measurement set up.

![Vector Network Analyzer](image)

**Fig 2.9. Cavity perturbation method setup**
In order to insert the material into the waveguide resonator, a non-radiating slot is constructed at the top of the waveguide. The length and width of the slot are 50 and 3 mm, respectively. The waveguide resonator is excited by TE_{10} mode. The dielectric material is inserted using the sample holder.

When the material under test (capillary tube with phantom equivalent fluid) is inserted in the resonator, the resonance peaks are shifted. The shifted resonance frequency is found using network analyzer at the maximum field position. In order to achieve this, sample is moved along the non-radiating slot with the help of a moving holder, till maximum shift to the lower frequency side. The real and imaginary parts of the dielectric constant are related to:

- the resonance frequency of the cavity with and without the sample,
- the volume ratio of the resonator and sample,
- the quality factors at resonance frequency with and without the sample.

Since the shift in resonance frequencies depends on the dielectric constant of the materials, the permittivity of each material is measured on that specific frequency. The complex relative permittivity of the material is given by

\[ \varepsilon_r' = 1 + \left( \frac{V_0 (f_0 - f_s)}{(f_s V_s)} \right) \]
\[ \varepsilon_r'' = \left( \frac{V_0}{4V_s} \right) \left[ \frac{1}{Q_s} - \frac{1}{Q_0} \right] \]

where
- \( f_0 \) = resonant frequency in the unperturbed cavity (cavity alone)
- \( f_s \) = resonant frequency in the perturbed cavity (cavity with sample)
- \( V_0 \) = volume of the waveguide cavity
- \( V_s \) = volume of the material sample
2.6 Electromagnetic simulation tools

Micro wave simulation (MWS) tools enable the fast and accurate analysis of high frequency devices such as antennas, filters, couplers, planar and multi-layer structures etc. The user friendly MWS quickly gives an insight into the EM behavior of high frequency designs.

2.6.1 3D Electromagnetic simulator HFSS

HFSS utilizes a 3D full-wave Finite Element Method (FEM) to compute the electrical behavior of high-frequency and high-speed components [7]. With HFSS, one can extract the parameters such as S, Y, Z, visualize 3D electromagnetic fields (near and far-field), and optimize design performance. An important and useful feature of this simulation engine is the availability of different kinds of port schemes. It provides lumped port, wave port, incident wave scheme etc. The simulation of coplanar waveguides and microstrip lines can be done using lumped port.

The optimization algorithm available with HFSS is very useful for antenna engineers to optimize the dimensions very accurately. There are many kinds of boundary schemes available in HFSS. Radiation boundary and PML boundary are widely used in this work. The vector as well as scalar representation of E, H, J values of the device under simulation gives a good insight into the problem under simulation.

The first step in simulating a system in HFSS is to define the geometry of the system by giving the material properties and boundaries for 3D or 2D elements available in HFSS window. The suitable port excitation scheme is then implemented. A radiation boundary filled with air is then defined surrounding the structure to be simulated. Now, the simulation engine can be invoked by giving the proper frequency of operations and the number of
frequency points. Finally the simulation results such as scattering parameters, current distributions and far field radiation pattern can be displayed.

2.6.2 Computer simulation Technology (CST microwave studio®)

CST MWS is based on Finite Integral Time-Domain technique (FITD) proposed by Weiland in 1976 [8]. It is the powerful and easy to use electromagnetic field simulation tool. Once the design of a mobile phone is finalized (assuming it in free space), the performance of the phone needs to be tested in more realistic surroundings such as near the human head. This is important since the field distribution and radiation pattern will be influenced by the human tissue. Finally the Specific Absorption Rate (SAR) also needs to be evaluated to fulfill the international mobile phone standard. The CST MWS transient solver provides an efficient Phantom head known as SAM Phantom head (SAM means "Specific Anthropomorphic Mannequin"). The head is modelled by a shell filled with a liquid which represents the average material properties of the head. So it can be easily used not only to design and optimize the antenna but also to check its performance in the presence of a human head and hand. The very high efficiency of the transient solver can be conveniently used with less simulation time. In just one simulation the broadband return-loss, the field distribution, the radiation pattern and the SAR-values for various frequencies can be determined.

2.7 Planar antennas-Review

This section presents different technologies so far proposed by the research groups across the world for the development of planar transmission line, planar antennas and coplanar wave guide fed (CPW) antennas for mobile applications. Due to the attractive features of direct integration with the final RF stage of the
communication system, various scientists and research groups are attracted by the printed antenna technology.

2.7.1 Planar transmission line

A conventional CPW (CoPlanar Wave guide) fed transmission line on a dielectric substrate consists of a centre strip conductor with semi-infinite ground planes printed on the same side of the conducting strip. CPW fed transmission lines are nothing but energy guiding devices that can be used to transfer electromagnetic signal from one part of the system to another. The relevant works in the field of coplanar wave guide fed transmission line and folded antennas are discussed in this section.

The CPW concept was proposed by Wen [9] in 1969. In the proposed structure two ground planes of width ‘w’ are parallel to the conducting strip. A zeroth-order quasi-static approximation has been employed to estimate the phase velocity and the characteristic impedance of the transmission line.

P. A. J. Dupuis.[10] reported the dependence of the characteristic impedance of a coplanar waveguide as a function of slot width and substrate thickness.


Design information for coplanar waveguide directional couplers using quasi-static zeroth order approximations was presented by Cheng P Wen [12]. The first analytic formulae for calculating quasi-static wave parameters of CPW’s have been studied using conformal mapping by Wen, [13].
Veyres and Fouad Hanna have extended the application of conformal mapping to CPW’s with finite dimensions and substrate thicknesses [14]. N. K. Das and D. M. Pozar [15] used the conformal mapping to derive the analytic formulae for CPW’s and CPS’s on multilayer substrates.

Analytic formula for the characteristics of coplanar transmission lines on multilayer substrates have been obtained using conformal mapping and the accuracy of this formula has been verified experimentally by Erli Chen and Stephen Y. Chou [16] on a variety of coplanar transmission lines using Differential Electro-Optic Sampling (DEOS).

Ching-Cheng Tien [17] reported the guiding characteristics of FW-CBCPW (Finite-Width Conductor-Backed Coplanar Waveguide) by the rigorous method of mode matching.

T. Kitazawa, Y. Hayashi and M. Suzuki proposed theoretical method for the analysis of a coplanar waveguide [18] with thick metal-coating which causes an increase in wavelength and a decrease in characteristic impedance.

A new analytical expression for the impedance and the permittivity of coplanar waveguides with lower ground plane is presented [19] by G. Ghione and C. Naldi.

Equivalent capacitances of coplanar waveguide discontinuities on multilayered substrates were calculated using a three-dimensional finite difference method by Mohsen Naghed [20].

William H. Hayd [21] reported the resonances and associated power loss which occurs in conductor backed coplanar transmission lines at selected frequencies from 1 to 230 GHz by three dimensional (3-D) EM simulations.
Circular Polarisation [22] (CP) radiation achieved from an asymmetric inductively coupling slot in the ground plane of the CPW feed line is discussed by Chih-Yu Huang and Ching-Wei Lingin.

Wen-Hua Tu [23] presented a coplanar waveguide-fed inductively coupled stepped-impedance slot antenna with 32% size reduction compared to the conventional uniform slot antenna, with better harmonic suppression.

Reconfigurable Defected Ground Structure (DGS) resonator fabricated on coplanar waveguide (CPW) technology is presented [24] by Heba B. El-Shaarawy, exploits the transversal dimension of the coplanar wave transmission line (CPW-TL) with four different states of the diode configuration.

Paper [25] presents the design and analysis of Compact Coplanar Waveguide (CPW)-fed Zeroth-Order Resonant (ZOR) antenna. Taehee Jang, Jaehyurk Choi, and Sungjoon Lim reported ZOR phenomenon to reduce the antenna size and composite right/left-handed (CRLH) unit cell on a vialess single layer, which simplifies the fabrication process.

2.7.2 Printed antenna design

The printed antenna was originally started in 1953 [26] when Deschamps proposed the use of microstrip feed lines to feed an array of printed antenna elements. Shortly thereafter, radiation from strip line discontinuities was reported by Lewin [27].

After the introduction of microstrip antenna, different methods of analysis for these antennas, including the transmission line model [28], the cavity model [29] and the spectral-domain method [30] were appeared.
A novel coupled line fed single-layer rectangular patch antenna is described by M.D. Van Wyk et al. [31]. This coupled line matching technique increases the bandwidth of the patch antenna by a factor of more than 2.5 as compared to the normal edge-fed patch with the same geometrical dimension.

A planar monopole broadband antenna with a parasitic radiator is proposed by Xing Jiang et al. [32]. The bandwidth of the monopole antenna is considerably improved with a parasitic element earthed with a matching inductor.

H.K. Kan et al. [33] presented a compact dual concentric ring printed antenna. Each ring is loaded by a localized dielectric layer and can therefore be optimized to operate at a certain frequency, thus enhancing the overall bandwidth of the antenna.

A novel folded monopole antenna is investigated numerically and experimentally by G. Ruvio et al. [34]. The proposed antenna comprises a short folded monopole suitably shaped at the base with two vertical grounding probes. This small antenna occupies impedance bandwidth up to 125% (1.6GHz to 7.5GHz) for a 10dB return loss.

The spectral domain full wave approach using Green’s function for the mixed dielectric nature of the microstrip antenna was proposed by Deshpande and Bailey [35]. The analysis of a rectangular patch and circular disc geometrics were studied using this method by Chew, Aberle and Bailey [36-37].

A circularly polarized rectangular microstrip antenna with a single point feed is also designed by Haneishi and Yoshida [38]. The narrow bandwidth of microstrip patch antennas are mitigated by using stacked patch radiators [39].

The Defected Ground Structures (DGS) are introduced on microstrip patch antennas to suppress the higher order harmonics are introduced by Y J Sung [40].
2.7.3 Planar Printed monopole antenna

There are a number of printed monopole antenna design can be found in the literature ranging from single band monopoles, multiband monopoles and ultra wideband antennas. The very basic design is in the form of a straight metallic conductor usually operated with one-quarter wavelength. But this design results large antenna height and it is impossible to integrate such an antenna in a compact communication gadget like mobile phone.

In order to reduce the height of the monopole a number of techniques such as bending, folding or wrapping two-dimensional planar monopoles to three-dimensional structures. These techniques reduce the total antenna height up to a large extent. Thus the development in the planar antenna design, resulted compact communication gadgets.

Printed monopoles are widely used in the case of compact applications due to the simplicity in design and optimum reflection and radiation performances. In this section some of the most relevant work on printed monopoles have been discussed.

S. Honda et al. [41] presented a circular disk monopole antenna with 1:18 impedance band width and omni-directional radiation characteristics. M.Hammoud et al. [42] proposed a circular disc monopole antenna having a large band width. The antenna provides a broad band width of 2.25-17.25 GHz for VSWR<2.

A.P Agrawall et al. [43] proposed a new configurations of wide band monopole antennas such as elliptical (with different ellipticity ratios), square, rectangular, and hexagonal disc. A simple formula is also proposed to predict the frequency corresponding to the lower edge of the band for each of these configurations.
Z. N. Chen presented [44] a new planar monopole antenna for broad band application. The antenna consists of a square parasitic planar radiator and a probefed strip, which are separated by a thin dielectric slab. The electromagnetic coupling of the planar radiator improves the impedance characteristics of a conventional monopole antenna.

A broadband triangular planar monopole is presented by Z. N. Chen et al.[45]. The equilateral triangular radiating sheet electromagnetically coupled with a probe-driven strip forms the EMC planar monopole. The antenna has the advantage of about 50% area reduction.

A type of annular planar monopole antenna is presented by Z. N. Chen et al.[46] and demonstrated that the proposed antennas are still capable of offering dramatically broad impedance bandwidths and acceptable radiation patterns even when more than half of the circular element of the structure has been removed.

Kin-Lu Wong et al. [47] developed a novel planar monopole antenna with a very low profile and capable of multiband operation. The proposed antenna is operated with the inner sub patch resonating as a quarter-wavelength structure and the outer one resonating as both a quarter-wavelength and a half-wavelength structure.

M. J. Ammann et al. [48] proposed a wide-band shorted planar monopole with beveling technique. A combination of beveling and shorting technique is used to increase the impedance bandwidth of the antenna.

A novel shorted, folded planar monopole antenna for application in GSM/DCS dual-band mobile phones is proposed by C.Y. Chiu in [49]. The antenna is shorted to the system ground plane, to improve impedance match.
A square planar monopole antenna including two feed points is developed by E. A. Daviu et al. [50]. Double feed is used in order to generate a pure and intense vertical current distribution in the whole structure and to avoid horizontal currents, which degrade the polarization properties and the impedance bandwidth performance of the antenna.

Jen-Yea Jan et al. [51] proposed a small planar monopole antenna with a shorted parasitic Inverted-L wire for wireless communications in the 2.4-5.2 and 5.8-GHz bands. The driven monopole element and shorted parasitic wire can separately control the operating frequencies of two excited resonant modes.

The application of genetic algorithm (GA) optimization to the design and analysis of planar monopole antenna is presented by Aaron J. Kerkhoff et al. [52]. Through analysis of the GA generated designs, it was shown that the wideness of the radiating element base and its close proximity to the ground plane cause the Reverse bow tie (RBT) to achieve a wider matching bandwidth with a reduced size compared with the conventional bow tie (BT).

Shun-Yun Lin [53] introduced a folded planar monopole antenna, which has a very low profile of about one twentieth of the wavelength of the lowest operating frequency. The effect is achieved by using a bended rectangular radiating patch and an inverted L-shape ground plane.

A square planar metal-plate monopole antenna fed by a novel trident shaped feeding strip is presented by Kin-Lu Wong et al. in [54]. With the use of the proposed feeding strip, the square planar monopole antenna studied shows a very wide impedance bandwidth of about 10 GHz 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).
Wang-Sang Lee et al. [55] proposed a Multiple Band-Notched Planar Monopole Antenna for Multiband Wireless Systems. The proposed antenna consists of a wideband planar monopole antenna and the multiple U-shape slots, producing band-notched characteristics. Wang-Sang Lee et al. [56] presented a wideband planar monopole antenna with dual band-notched characteristics. In order to generate dual band-notched characteristic, they proposed nine types of planar monopole antennas, which have two or three shaped slots (or inverted L) in the radiator. This technique is suitable for creating ultra-wideband antenna with narrow frequency notches or for creating multiband antennas.

Sheng-Bing Chen et al. [57] proposed a modified T-shaped planar monopole antenna for multiband operation. In the proposed antenna, two asymmetric horizontal strips were used as additional resonators to produce the lower and upper resonant modes. An ultra-wideband (UWB) planar monopole antenna with a tunable bandnotched response is proposed by E. Antonino-Daviu et al. in [58]. Tuning of the rejected frequency is realized by loading an embedded resonant slot with a varactor.

### 2.7.4 Coplanar Waveguide Fed monopole Antennas

Coplanar wave guide has become an attractive feeding technique and can be effectively utilized in the design of compact printed antenna designs. CPW antennas have many features, such as easy fabrication and integration with monolithic microwave integrated circuits. CPW employs a simplified configuration with a single metallic layer. The key features of Coplanar Wave Guide monopole are the availability of ground in the same plane and good transfer characteristics. This figured the scientists all over the world. As such, relevant papers in this area are summarized in the following section.
A CPW-fed dual frequency monopole antenna has been presented by Horng-Dean Chen et al. [59]. The proposed antenna utilizes the advantages of the CPW line to simplify the structure of the antenna into a single metallic level, thereby making easier for integration with the microwave integrated circuits. The antenna consists of a combination of two monopoles connected in parallel at the feed point, each operating at a specified frequency mode.

K. Chung et al. [60] presented a wideband CPW-fed monopole antenna with parasitic elements and slots. The wide bandwidth is achieved by adding two parasitic elements along the length of the monopole and three narrow slots.

W.C. Liu [61] presented a new design of a planar monopole antenna consisting of a rectangular microstrip patch with a rectangular notch. The antenna is fed by a coplanar waveguide (CPW) line such that only a single-layer substrate is required for this antenna. To produce dual frequency wide impedance band behavior a notch is introduced to the radiating patch. He has also presented a paper on broadband dual-frequency meandered CPW-fed monopole antenna [62]. The antennas were developed to widen the narrow bandwidth of the coplanar patch antenna. This was achieved by inserting a meandered line between the 50 ohm CPW lines and radiating patch.

A novel wideband dual-frequency design of a coplanar waveguide (CPW)-fed monopole antenna is proposed by W.C. Liu [63]. The antenna comprises a planar patch element with a sided L-shaped slit to become a double inverted-L monopole and is capable of generating two separate resonant modes with good impedance match.

J. Liang et al. [64] presented a study of coplanar waveguide (CPW) fed circular disc monopole antenna for ultra-wideband (UWB) applications. It has
been shown that the feed gap, the width of the ground plane, and the dimension of the CPW-fed circular disc monopole antenna are the most important parameters that determine the performance of the antenna.

A miniature dielectric loaded monopole antenna fed by coplanar waveguide is proposed by Yi-Fang Lin et al. in [65] for WLAN applications in the 2.4/5-GHz bands. The proposed antenna has small size, effective feeding structure and adequate operational bandwidth, such that it is suitable for use in WLAN applications.

The analysis of a new printed antenna is presented by V. Zachou et al. [66]. 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.

A simple and compact ultrawideband (UWB) aperture antenna with extended band-notched designs was presented by Yi-Cheng Lin et al. [67]. The antenna consists of a rectangular aperture on a printed circuit board ground plane and a T shaped exciting stub. The proposed planar coplanar waveguide fed antenna is easy to integrate with radio-frequency/microwave circuitry for low manufacturing cost.

M.-T. Zhang et al. [68] developed a dual-band CPW-fed folded-slot monopole antenna for RFID application. A coplanar waveguide fed monopole antenna for 5 GHz wireless communication is proposed by W. C. Liu [69]. The proposed antenna consists of a hook strip, CPW feeding structure with a rectangular ground and an inverted L-shaped ground. The antenna has compact size, good impedance bandwidth and good radiation characteristics suitable for
Joon Il Kim developed [70] an ultra wideband coplanar waveguide fed LI-shape planar monopole antenna. The proposed antenna consists of an L-shaped monopole and an I-shaped open stub monopole connected at the end of a CPW feed line.

A novel dual-band design of a CPW fed monopole antenna with a cross slot was proposed by C.M. Wu [71]. The antenna, comprising a planar patch element embedded with a cross slot, is capable of generating two separate resonant modes with good impedance match. The CPW-feed technology is applied to the design.

T.A. Djaiz developed [72] a CPW-fed miniaturized antenna with bandwidth enhancement for biomedical localization applications. A meander arm is used as the radiating element and an additional layer as superstrate to reduce the antenna area to improve the performance in terms of bandwidth.

To achieve dual-band antenna performance with less interdependency of the two operation bands, a dual-band CPW-fed slot monopole hybrid antenna with orthogonal polarizations was proposed by Xian-Chang Lin [73]. Guorui Han presented [74] a novel compact dual-band CPW-fed antenna with a microstrip stub. The proposed dual-band antenna works at 2.4 GHz and 5.8 GHz simultaneously.

The pulse preserving capabilities of the CPW-fed circular disk monopole antenna with improved correlation factor of 7% by selecting suitable substrate parameters are discussed by Q.Wu [75]. The ringing and pulse-width spreading of the radiated signals caused by the energy-storage effects of the dielectric substrate are also discussed.
Chapter 2

Simple and compact CPW-fed planar monopole antenna for ultra-wideband applications with a gourd-like radiation element and a modified stair-style ground is reported by Y.B. Yang [76]. The antenna exhibits a nearly omnidirectional radiation pattern, stable antenna gain, and good time-domain characteristics across the operation band.

Novel coplanar waveguide-fed monopole UWB antenna and a miniaturized version of an asymmetric coplanar strip-fed half monopole antenna is reported by P Fei[77].

2.8 Mobile antenna with reduced user interference – review

The large amount of electromagnetic radiation everywhere in the environment has increased the concern about the possible health risks of wireless devices. Rising from these aspects, antenna designers have been forced to pay a growing amount of interest in reducing the radiation absorbed by the user. Different methods are used for reducing this type of radiations. Adding an external shield to mobile phones is the most common method adopted for reducing the unnecessary radiations. Here shielding structure has to be integrated with the antenna to provide better shielding effectiveness. Material selection and position of the external shield is also very important. A ferrite sheet attached to the front side, close to head can also reduce radiation. However, the parameters such as attaching location, size and material properties of ferrite sheet played an important role in the reduction effectiveness. Highly directive antennas can also reduce radiation towards human head significantly. However, the adoption of highly directive antennas certainly causes degradation in signal reception from other directions. Parasitic elements are also used to get end fire pattern. Complicated truncated ground plane is used to get end fire pattern throughout the operating band. Large reflectors are also used to reduce
radiations. Researchers have explored PIFA (Planar Inverted F Antenna) with EBG (Electromagnetic Band Gap) surface on the ground plane to reduce radiation towards human head. But this deteriorates the structure simplicity and compactness, and also there is no appreciable reduction in radiation towards human head.

This section presents different technologies so far proposed by the research groups across the world for the development of antennas for mobile applications with less effect on human body.

Andi Hakim Kusuma et.al[78] proposed a novel low SAR dual-band PIFA structure operating at 0.9 GHz and 1.8 GHz bands. They are considered, to reduce exposure of electromagnetic radiation towards the human head. The SAR reduction is accomplished by inserting a thin metallic layer between the patch and the ground plane and to reduce the current flowing in the ground plane. This layer is connected to the ground plane through few posts located at selected optimum positions. Additionally, three vertical sidewalls are used to reduce radiation from the patch to the human head. Results show that the proposed structure can reduce SAR up to 76%.

In the reported work by R. Augustine et.al[79],flexible polymeric ferrite sheets are characterised on the basis of their shielding efficiencies. SAR measurements were carried out with a planar wearable antenna and polymeric ferrite shielding to confirm its competence. A low profile, conformal antenna has been designed to resonate at 2.4 GHz. Specific absorption rate is reduced by polymeric ferrite sheets which are particularly attractive as they are low profile, flexible and conformal. So the antenna could be thought of to be printed on them to attain certain flexibility in its use. Polymeric ferrite sheets will be best suited for RFID (868 MHz) application where antennas are made of metallic
ink and deposited on a plastic sheet. The characteristics of ferrite will lead to the miniaturization of antennas.

The electromagnetic interaction between the antenna and the human head is reduced with materials and metamaterials. The reduction of Specific Absorption Rate (SAR) with materials and metamaterial is performed by the finite-difference time-domain method with Lossy-Drudemodel by CST Microwave Studio by Mohammad Tariqul Islam et. al[80]. The metamaterials can be obtained by arranging split ring resonators (SRRs) periodically. The SAR value has been observed by varying the distances between head model to phone model, different width, different thickness, different height of material and metamaterial design. Materials has achieved 47.18% reduction of the initial SAR value while metamaterial achieved a reduction of 42.12%. These results can provide helpful information in designing the mobile communications equipments for safety compliance.

K H Chan et. al[81] studied spherical phantom heads by the use of a reduced-size on the the (SAR) calculation, which is usually extremely complicated and time demanding. Antenna performance and the SAR value were studied by using the Finite- Difference Time-Domain (FDTD) method. Results have shown that both the return loss and the radiation pattern of the mobile phone antenna are only slightly affected by the fractional head model for almost all cases when the phantom head is truncated to not more than 25% in volume. Results have also indicated that the percentage difference in the SAR value for the full head model and the fractional head model is less than 5%.

In the paper by L.K.Ragha[82] et. al has introduced a radio frequency (RF) shield on dipole antenna to reduce SAR in the implanted spherical head model. RF shields made of ferrimagnetic material are used to suppress surface
current on antenna. Conducting cylindrical implant of resonant length is embedded eccentrically into a head model and it is irradiated by dipole antenna (0.4wavelength) at 900 MHz. Effect of wireless device on implanted head and SAR reduction techniques to minimize fears of patients are discussed. Simulations are performed to find the effect of RF fields on implanted medical device by varying its parameters like length and location using CST-Microwave studio. Paper includes numerical evaluation of the SAR reduction using RF shield and also analyzes the SAR data for shielding effectiveness. Drastic reduction in SAR was observed in case of Ferrite3 material of 1mm thickness when both implant location and length were varied. Simulation results will be useful for compliance testing of wireless communication devices.

The paper by K. H. Chan et.al[83] provides an experimental study on the effectiveness of SAR reduction by attaching conductive materials to mobile phones, and the corresponding effects of the antenna performance of the mobile phones. The results show a typical trade-off of a 20% reduction in the SAR value with a maximum 1.8dB reduction in the received power of the antenna. The results also conclude that the position of the shielding material is an important factor, whereby the hot spot of the SAR distribution of the mobile phone must be well covered in order to achieve good SAR reduction.

M.A. Mangoud et.al [84] presented a two-element phased antenna array for mobile handset using the FDTD hybrid method. The array is designed to provide a spatial null in the near field zone in the direction of the human head. Compared with an omnidirectional antenna, the overall efficiency and azimuth coverage are improved and the peak specific absorption rate in the head can be reduced by at least 10dB.
Denise L. Hamblin et al. investigated the influence of EEG electrode caps on SAR in the head from a GSM900 mobile phone (217-Hz modulation, peak power output 2 W). SAR measurements were recorded in an anthropomorphic phantom using a precision robotic system. Peak 10 g average SAR in the whole head and in just the temporal region were compared for three phantom arrangements; no cap, 64-electrode “Electro-Cap,” and 64-electrode “Quick-Cap”. Relative to the “no cap” arrangement, the Electro-Cap and Quick-Cap caused a peak SAR (10 g) reduction of 14% and 18% respectively in both the whole head and in the temporal region. Additional computational modeling confirmed that SAR (10 g) is reduced by the presence of electrode leads and that the extent of the effect varies according to the orientation of the leads with respect to the radiofrequency (RF) source. The modeling also indicated that the nonconductive shell between the electrodes and simulated head material does not significantly alter the electrode lead shielding effect.

Cheng Tse Lee and Kin-Lu Wong presented an internal wireless wide-area network (WWAN) antenna suitable for GSM850/900/1800/1900/UMTS operation in the clamshell mobile phone with reduced ground plane effects. Small variations in the performances of the antenna for the clamshell mobile phone in the open state (talk condition) and closed state (idle condition) are obtained. This is owing to the reduced effects of the upper (cover) ground plane on the performances of the internal antenna obtained by embedding a slit at the edge of the upper ground plane close to the connecting strip between the two (upper and main) ground planes of the clamshell mobile phone. In this case, large surface currents excited around the slit are achieved, with other portions of the upper ground plane showing much weaker surface current distributions, which makes the embedded slit behaves like a current trap for the excited surface currents. This condition results in reduced effects of the upper ground plane. This also
makes the near-field radiation of the clamshell mobile phone with the proposed
antenna easily meet the specific absorption rate (SAR) and hearing aid
compatibility (HAC) specifications required for practical applications.

A new conformal antenna for hand held mobile telephones is proposed by
H.0 Ruoss and F.M. Landstorfer[87]. The slot antenna is investigated with a
modified method of moments. It enables an accurate modelling of the slot and
calculate input impedance as well as electric and magnetic near and far fields
taking the influence of the user’s head and hand into consideration. The
interaction with the human body can be reduced significantly.

Jiunn-Nan Hwang and Fu-Chiarng Chen [88] performed the preliminary
study of SAR reduction with metamaterials by the finite-difference time-
domain method with lossy Drude model. It is found that the SAR in the head
can be reduced by placing the metamaterials between the antenna and the head.
The antenna performances and radiation pattern with metamaterials are
analyzed. A comparative study with other SAR reduction techniques is also
provided. The metamaterials can be obtained by arranging SRRs periodically.
In this research, the SRRs are operated at 900 and 1800 MHz bands. The design
procedure is described. Numerical results of the SAR values in a muscle cube
with the presence of SRRs are shown to validate the effect of SAR reduction.
These results can provide helpful information in designing the mobile
communication equipments for safety compliance.

Andi Hakim Kusuma et.al[89] proposed a novel low SAR PIFA structure
to reduce exposure of the human head to mobile-set antenna radiation. Dual-
band PIFA structures operating at 0.9 GHz and 1.8 GHz bands are considered.
SAR is decreased by reducing the back-radiation coming from the patch and the
ground plane. This SAR reduction is accomplished by inserting a thin metallic
layer between the patch and the ground plane to reduce the current flowing in the ground plane. This layer is connected to the ground plane through few posts located at selected optimum positions. Additionally, three vertical sidewalls are used to reduce radiation from the patch to the human head. Results show that the proposed structure can reduce SAR up to 76%.

In the reported work by R. Augustine et.al [90] flexible polymeric ferrite sheets are characterised on the basis of their shielding efficiencies. SAR measurements are carried out with a planar wearable antenna and polymeric ferrite shielding to confirm its competence.

The paper by K. H. Chan et.al[91]provides an experimental study on the effectiveness of SAR reduction by attaching conductive materials to mobile phones. The corresponding effects of the antenna performance are discussed elaborately. The results show a typical trade-off of a 20% reduction in the SAR value with a maximum 1.8dB reduction in the received power of the antenna. They conclude that the attachment position of the shielding material is an important factor.

In the paper by L.K.Ragha and M.S.Bhatia [92] proposed radio frequency (RF) shields on mobile phone to reduce SAR in spherical head model. Shields made of ferrimagnetic materials are used to suppress surface currents. Many kinds of simulation are performed to investigate the effect of various parameters like location, size, shape and thickness of the shield on the SAR and also on the antenna performance. Paper includes numerical evaluation of the SAR reduction and also analyzes the SAR data for shielding effectiveness.

S.I. Kwak[93] performed experimental tests of SAR reduction on a mobile phone. To protect a human head from exposure to electromagnetic fields
and comply with exposure guidelines, the electromagnetic bandgap (EBG) structures are inserted in a commercial personal communication services (PCS) mobile phone. The measured results demonstrate the movement of hot spots and the reduction of SAR in the human head.

In the paper by M. B. Manapati and R. S. Kshetrimayum [94], single negative metamaterial is used to reduce the electromagnetic interaction between the mobile phone and human head. The specific absorption rate in the head can be reduced by placing the metamaterials between the antenna and the head. Single negative metamaterials from periodic arrangement of split ring resonators (SRRs), spiral resonators (SRs) and open split ring resonators (OSRRs) are employed. By properly designing structural parameters of SRRs, the effective medium parameter can be made negative around 900MHz and 1800MHz bands. The design procedure and principle operation of resonators are explained. The performance and size comparison of resonators are described. Numerical results of the SAR values in the human head with the presence of resonators exhibit SAR reduction. These results can provide useful information in designing safety mobile communication equipments.

An attempt to solve the problem of electromagnetic wave hazard caused by the radiation from handset mobile antenna as well as the problem of the handset mobile operation with differently tuned frequencies was suggested by Marai M. Abousetta[95].

Weiping Dou investigated the chassis influence on the SAR characteristics of handset antenna with the finite-difference time domain method [96]. The chassis is conductive and equipped with a quarter-wavelength monopole. The optimal chassis sizes have been presented for 900 MHz and 2 GHz operation.
S V Amos [97] raised important aspects concerning SAR modelling and reduction techniques necessary to comply with industry standards. From studies the following points have been concluded: The ear is an important parameter in the design model used in simulations. A standard model would be beneficial so that comparisons can be drawn. Parameters such as the amount of shielding can, feed position and electrical parameters of tissues may all have significant effects on the resulting SAR. Increased distance between the radiating element and head can significantly reduce SAR.

A new design using a dielectric reflector to reduce the back radiation of aperture coupled antennas is proposed and developed [98] by Qinjiang Rao et.al. To validate the proposed design, a concise theory analysis is first conducted and then the proposed design is analyzed in a modified aperture coupled microstrip antenna. In this design, a radiating patch and a microstrip feed line are etched on the same side of a top substrate and a coupled slot is etched on the opposite side of this substrate. To examine the effect of the dielectric reflector on the antenna performance, theoretical simulations and experimental investigations were carried out. A good agreement between the theoretical expectation and the measured results validates the proposed design. The measured radiation patterns show that the proposed structure can offer high radiation efficiency, a high front to back radiation ratio, and a high co-cross polarization ratio. With these features, the proposed design is significant in the electromagnetic interference and electromagnetic compatibility (EMI/EMC) designs for reduced undesirable radiation.

The paper by Sang il Kwak[99] proposed a optimized multilayer PIFA in PCS bands based on the EBG for SAR reduction. The EBG structure which has band gap capability and acts as PMC surfaces can reduce the surface waves and
Methodology and Antenna Review

prevents the undesired radiation from the antenna. Thus, the EBG structure can reduce the electromagnetic fields toward the human head direction. Optimization of multilayer PIFA structure using the EBG structure is conducted for S parameters, radiation patterns and on the SAR values. A parametric study of location and height of a PIFA with the EBG structure is performed. The results demonstrated the reduction of SAR value without sacrificing the antenna performance.

An efficient electrically small wide band planar antenna for Specific Absorption Rate is designed by Jung-han Kim [100]. The proposed antenna consists of two inductive loading arms and inverted L–type monopole antenna. Also, the proposed antenna is designed to have a CPW feed structure and a superstrate layer. Two inductive loading arms are electromagnetically coupled with main monopole for the dual resonance mode of the antenna operation. The dual resonance characteristics are shown at 2.184GHz and 2.44GHz, respectively. The measured impedance bandwidth (VSWR ≤ 2) is 624 MHz (1.984~2.608 GHz). The maximum gain of 2.8 dBi and radiation efficiency of 80.3 % at 2.184 GHz is observed. With this arrangement the proposed antenna is mounted at the front of the mobile handset cover plane. The radiated power difference between the forward and backward directions is about 10dBi. Moreover, disadvantage of the conventional electrically small antenna, such as narrow impedance bandwidth and radiation efficiency, are improved by simple inductive loading structure.

Filippo Costa et.al used [101] High-Impedance Surfaces (HIS) comprising lossy Frequency Selective Surfaces (FSS) to design thin electromagnetic absorbers. The structure, despite its typical resonant behavior, is able to perform a very wideband absorption for reduced thickness. Losses in the frequency
selective surface are introduced by printing the periodic pattern through resistive inks and hence avoiding the typical soldering of a large number of lumped resistors. The effect of the surface resistance of the FSS and dielectric substrate characteristics on the input impedance of the absorber is discussed by means of a circuit model. It is shown that the optimum value of surface resistance is affected both by substrate parameters (thickness and permittivity) and FSS element shape. The equivalent circuit model is then used to introduce the working principle of the narrowband and the wideband absorbing structures.

Dan Sievenpiper et.al[102] introduced a new type of metallic electromagnetic structure that is characterized by having high surface impedance. Although it is made of continuous metal, and conducts dc currents, it does not conduct ac currents within a forbidden frequency band. Unlike normal conductors, this new surface does not support propagating surface waves, and its image currents are not phase reversed. The geometry is analogous to a corrugated metal surface in which the corrugations have been folded up into lumped-circuit elements, and distributed in a two-dimensional lattice.

Ming-Shing Lin et.al[103] used HIS to reduce interaction between a wireless antenna and its user. Mushroom and Jerusalem Cross HIS structures were designed for the PCS band (1.8 GHz). The performance of these HIS structures were investigated by surface-wave and reflection-phase methods. A new test method was also proposed to characterize the reflection phase of an HIS by using a GTEM cell. The effects of HIS sheets on antenna performance and the SAR were studied. Results revealed that these HIS structures can reduce SAR values.

Cavity resonance antennas with dielectric superstrate are considered with different ground plane types namely, Perfect Electric Conductor (PEC), Perfect Magnetic Conductor (PMC), and Artificial Magnetic Conductor (AMC) by
Alireza Foroozesh et.al[104]. It is shown that the effects of angular and polarization dependency of artificial ground planes can be beneficial or detrimental to the antenna performance especially for directivity.

In a communication by I. Gallego-Gallego[105], the combination of soft surfaces with traditional microstrip patch antennas for reducing the level of back radiation in wearable applications has been proposed. The studies have been extended to the case of cylindrical antenna shape to take into account the conformability required for the textile antenna.

A new type of metallic electromagnetic structure has been reported by D. Sevenpiper [106] that is characterized by having high surface impedance. Unlike normal conductors, this new surface does not support propagating surface currents, and it reflects electromagnetic waves with no phase reversal. They suggested that unique material can serve as the ground plane for new kinds of low-profile antennas.

The design of a meta-material realization of AMC surfaces for a high-gain reflector antenna application is presented by Jwo-Shiun Sun et.al[107]. Artificial materials of periodic dielectrics exhibiting an EBG performance have been proposed and applied to planar inverted-F antenna. The Artificial Dielectric Material (ADM) can enhance antenna radiation performance, spread antenna bandwidth and improve antenna radiation gain and efficiency. The artificial defected dielectric material has useful characteristics of harmonic rejection, band suppression and surface wave suppression.

An AMC surface, comprised of Hilbert and/or Peano space- filling curve inclusions is utilized as a thin electromagnetic absorber by John McVay et.al[108]. Numerical results are presented to show the effects of the incident
angle, conducting strip widths and substrate thicknesses on the absorbing properties of such surfaces. The performance of a fabricated thin absorber in reducing the RCS of a conducting plate is demonstrated through measurement.

The paper by Ricardo Gómez-Villanueva et.al reviews the different methods employed in the last years for the development of low SAR antennas inside portable terminals of mobile phone systems[109]. Specifically, auxiliary antenna elements, ferrite loading, EBG/AMC surfaces and metamaterials techniques are examined. From the methods reviewed the EBG and metamaterial techniques appear as feasible low SAR options that need more study to improve the size and bandwidth parameters that limits their use.

An artificial magnetic conductor using the SRRs printed on conductor-backed dielectric substrate is presented by Chen, Z N et.al[110]. The simulation and measurement verify that the magnetic conductor is successfully accomplished around the resonant frequency. As an antenna application, the characteristics of a horizontal wire antenna placed above the SRR array, as well as a conducting ground plane and a grounded dielectric slab, are investigated and compared. A maximum gain of 4.34 dBi is obtained for the wire antenna above the SRR array. The results confirm that the split resonators can successfully be used to replace the antenna ground plane in order to improve their performance.

2.9 Chapter conclusion

This chapter has discussed the methodology to simulate, optimize and fabricate the various mobile antennas mentioned in the following chapters of the thesis. The simulation and measurement techniques used to study the performances of the antennas in the near field and far field are discussed. Finally a detailed literature review of CoPlanar waveguide fed antennas and mobile antennas with reduced user interference also conducted.
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