This chapter starts with a brief overview of electromagnetic spectrum and its classification based on types of radiation. The progress in microwave communication system and various wireless communication bands used are discussed in this chapter. The different antennas, which are the most essential components of any wireless communication system, are also discussed. Various analytical techniques used for the analysis of the antenna are also addressed in this chapter. Finally, the motivation behind the development of mobile antenna with reduced RF interference is presented. The chapter concludes with the description of the organization of the subsequent chapters.
1.1 Introduction

Wireless and mobile communication industry made a revolutionary remark in the 21st century with the development of modern communication equipments having ultra compact size with multi features. The driving force behind wireless communication is the promises of portability, mobility and accessibility. It has an enormous impact on daily life. ‘Antennas’ the key element in wireless communication devices had undergone amazing developments especially in the direction of compactness and safety aspects. In general, an antenna is used to either transmit or receive electromagnetic waves. It is a transition device or a transducer between a guided wave and a free space wave or vice versa. Antennas have found several important applications in the entire radio frequency range. Modern antennas or antenna systems require careful design through thorough understanding of the radiation mechanism of electromagnetic waves.

1.2 Electromagnetic radiations

Electromagnetic radiation (abbreviated as EM radiation or EMR) is a form of energy which exhibits wave like behavior and travels through space with a velocity of light. These EM waves consist of electric and magnetic components, which oscillate perpendicular to each other and moves through space at the speed of light. Different forms of electromagnetic energy are categorized by their wavelengths or frequencies. The different parts of the radio spectrum are used for different radio transmission technologies and applications as shown in Table 1.1 Radio waves and microwaves are part of this electromagnetic spectrum.
### Table 1.1. Parts of Radio spectrum [1]

<table>
<thead>
<tr>
<th>Band name</th>
<th>Abbreviation</th>
<th>ITU band</th>
<th>Frequency and wavelength in air</th>
<th>Example uses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tremendously low frequency</td>
<td>TLF</td>
<td>&lt;3kHz &gt; 100,000 km</td>
<td>Natural man-made electromagnetic noise</td>
<td></td>
</tr>
<tr>
<td>Extremely low frequency</td>
<td>ELF</td>
<td>3-30kHz 100,000 km – 10,000 km</td>
<td>Communication with submarines</td>
<td></td>
</tr>
<tr>
<td>Super low frequency</td>
<td>SLF</td>
<td>30-300kHz 100,000 km – 1000 km</td>
<td>Communication with submarines</td>
<td></td>
</tr>
<tr>
<td>Ultra low frequency</td>
<td>ULF</td>
<td>300-3000kHz 1000 km – 100 km</td>
<td>Submarine communication, Communication within mines</td>
<td></td>
</tr>
<tr>
<td>Very low frequency</td>
<td>VLF</td>
<td>3-30 kHz 100 km – 10 km</td>
<td>Navigation time signals, submarine communication, wireless heart rate monitors, geophysics</td>
<td></td>
</tr>
<tr>
<td>Low frequency</td>
<td>LF</td>
<td>30-300 kHz 10km – 1 km</td>
<td>Navigation time signals, AM longwave broadcasting (Europe and parts of Asia), RFID, amateur radio</td>
<td></td>
</tr>
<tr>
<td>Medium frequency</td>
<td>MF</td>
<td>300-3000 kHz 1km – 100m</td>
<td>AM (medium-wave) broadcasts, amateur radio, avation beacon</td>
<td></td>
</tr>
<tr>
<td>High frequency</td>
<td>HF</td>
<td>3-30 MHz 100m – 10m</td>
<td>Shortwave broadcasts, citizen’s band radio, amateur radio and over – the horizon avionics communications, RFID, Over-the-horizon radar, Automatic link establishment (ALE)/Near Vertical incidence Skywave (NVIS) radio communications, Marine and mobile radio telephony</td>
<td></td>
</tr>
<tr>
<td>Very high frequency</td>
<td>VHF</td>
<td>30-300MHz 10m-1m</td>
<td>FM television broadcasts and line-of-sight ground-to-aircraft and aircraft-to-television communications, Land Mobile and Maritime Mobile communications, amateur radio, weather radio</td>
<td></td>
</tr>
<tr>
<td>Ultra high frequency</td>
<td>UHF</td>
<td>300-3000MHz 1m-100mm</td>
<td>Television broadcasts, microwave ovens, microwave devices/communications, radio astronomy, mobile phones, wireless LAN, Bluetooth, ZigBee, GPS and two way radios such as Land Mobile, FRS</td>
<td></td>
</tr>
<tr>
<td>Super high frequency</td>
<td>SHF</td>
<td>3-30GHz 100mm – 10mm</td>
<td>Radio astronomy, microwave devices/communications, wireless LAN, most modern radars, communications satellites, satellite television broadcasting, DBS, amateur radio</td>
<td></td>
</tr>
<tr>
<td>Extremely high frequency</td>
<td>EHF</td>
<td>30-300GHz 10mm-100mm</td>
<td>Radio astronomy, high-frequency microwave radio relay microwave remote sensing, amateur radio directed-energy weapon, millimeter wave scanner</td>
<td></td>
</tr>
<tr>
<td>Terahertz or Tremendously high frequency</td>
<td>THz or THF</td>
<td>300-3,000GHz 1mm-1000m</td>
<td>Terahertz imaging – a potential replacement for X-rays in some medical applications, ultrafast molecular dynamics, condensed-matter physics, terahertz time-domain spectroscopy, terahertz computing/communications, sub-mm remote sensing, amateur radio</td>
<td></td>
</tr>
</tbody>
</table>
1.2.1 Frequency range of spectrum

Generally, electromagnetic radiation is classified by their wavelength into radio wave, microwave, terahertz (or sub-millimeter) radiation, infrared, visible light, ultraviolet, X-rays and gamma rays. The radio frequency (RF) part of the electromagnetic spectrum is generally defined as that part of the spectrum where electromagnetic waves have frequencies in the range of about 3 kilohertz (3 kHz) to 300 gigahertz (300 GHz). In the order of increasing frequency or decreasing wavelength, different electromagnetic radiations in an electromagnetic spectrum are shown in figure 1.1.

![Increasing frequency (f) →

Increasing wavelength (λ)←

Fig.1.1. Radio waves in Electromagnetic Spectrum](image)

According to the International Telecommunication Union (ITU) radio bands defined in the ITU Radio Regulations, states that "the radio spectrum shall be subdivided into nine frequency bands, which are designated by progressive whole numbers" [1]. The frequency bands as per ITU are shown in table 1.2. Each band is given a number, in which the number is the logarithm of the approximate geometric mean of the upper and lower band limits in Hz.
Table 1.2. ITU radio bands of the Electromagnetic spectrum

<table>
<thead>
<tr>
<th>Band Number</th>
<th>Symbols</th>
<th>Frequency Range</th>
<th>Wavelength Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>VLF</td>
<td>3 to 30 kHz</td>
<td>10 to 100km</td>
</tr>
<tr>
<td>5</td>
<td>LF</td>
<td>30 to 300kHz</td>
<td>1 to 10km</td>
</tr>
<tr>
<td>6</td>
<td>MF</td>
<td>300 to 3000kHz</td>
<td>100 to 1000m</td>
</tr>
<tr>
<td>7</td>
<td>HF</td>
<td>3 to 30 MHz</td>
<td>10 to 100m</td>
</tr>
<tr>
<td>8</td>
<td>VHF</td>
<td>30 to 300 MHz</td>
<td>1 to 10m</td>
</tr>
<tr>
<td>9</td>
<td>UHF</td>
<td>300 to 3000 MHz</td>
<td>10 to 100cm</td>
</tr>
<tr>
<td>10</td>
<td>SHF</td>
<td>3 to 30 GHz</td>
<td>1 to 10cm</td>
</tr>
<tr>
<td>11</td>
<td>EHF</td>
<td>30 to 300 GHz</td>
<td>1 to 10mm</td>
</tr>
<tr>
<td>12</td>
<td>THF</td>
<td>300 to 3000 GHz</td>
<td>0.1 to 1mm</td>
</tr>
</tbody>
</table>

The most important use of RF energy is for telecommunications services. Radio & television broadcasting, cellular telephones, radio communications, amateur radio, microwave point-to-point links, and satellite communications are some telecommunication applications. Microwave oven, radar, industrial heating and sealing are some of the noncommunication uses of RF energy.

1.2.2 Ionizing and Non ionizing radiations

The electromagnetic radiations are divided into two types. Ionizing radiations and Non ionizing radiations. Electromagnetic radiation is designated as non-ionising when the frequency is below $10^{15}$ Hz (wavelength $\lambda=10^{-8}$ to $10^4$ m) and as ionising at higher frequencies. Radiation that has energy to move atoms in a molecule around or cause them to vibrate, but not carry enough energy to remove electrons, is referred to as "non-ionizing radiation". Instead of producing charged ions when passing through matter, non-ionizing radiation induces electric fields and currents and can generate heat. Thus, this radiation is
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not directly interfering with DNA but it can increase tissue temperature at high exposure [2]. Sound waves, RF signals, microwave signals, infrared light, and visible light are the examples of non ionizing radiations. Whereas ionizing radiation has enough energy to remove tightly bound electrons from atoms, thus creating ions. Ultra violet, X-ray, Nuclear and Gamma rays come under ionizing radiation and which are more harmful than non-ionizing radiation. Figure 1.2 shows different types of radiations in the electromagnetic spectrum.

![Fig 1.2. Types of radiations in Electromagnetic spectrum](image)

The electromagnetic fields have a great influence on the behavior of all living systems. Biological effects that result from heating of tissue by RF energy are often referred to as "thermal" effects. This heating effect from RF devices mainly focused on RF absorption by the head, particularly from mobile handsets. Thus the possible physiological damage in human beings from EM wave exposures is due to temperature increase. The temperature increase of 4.5 °C in the brain has been remarked to be an allowable limit,
which does not lead to any physiological damage (for exposures of more than 30 minutes) [2]. The heating effects in biological tissue escalate with the increase in frequency, even though the heat's penetration depth in the tissue decreases.

1.2.3 Exposure to RF radiation

Wireless and mobile communication is one of the fastest growing areas of modern world. It has an enormous impact on our daily life.

The biological effects and health implications of RF & microwave radiation associated with cellular mobile telephones or wireless systems have become a focus of international scientific interest. Even though our knowledge regarding the biological effects of RF and microwave radiation has increased considerably, the scientific evidence on health effects of RF and microwave radiation associated with these wireless devices is still tentative. The overall evidence from case control and cohort studies of phone usage suggests that there are large increased risks of intracranial tumors, or other cancers, in relation to cellular phone use for a long period [4]. Rising from these aspects, antenna designers have been forced to pay a growing amount of interest in reducing the radiation towards the user. The reduction of power absorbed by the user reduces potential health hazards.

1.3 Glimpse through history of microwave communication

Wireless communication history starts with Hertz when he proved Maxwell's theoretical prediction of electromagnetic waves by his classical experiments in 1880s [5]. In 1896 Guglielmo Marconi demonstrated wireless telegraph to English telegraph office [6]. In the preceding years, 1894-1900 the generation and use of millimeter wave for communication has performed by
Jagadish Chandra Bose with the first Horn antenna [7]. Over the past century research in wireless communication has witnessed remarkable revolution. The modern wireless technology allows simultaneous transmission of multiple channels of television, radio, video and audio to a range of multi-media devices including mobile phones, PDA, PCs and other handheld devices. The need to develop an efficient public mobile communication system has been driving a lot of researchers. Guglielmo Marconi gained a patent for his wireless telegraph in 1909[8]. The competitive rush to design and implement digital systems led again to a variety of standards such as GSM (Global System Mobile), TDMA (Time Division Multiple Access) PDC (Personal Digital Cellular) and CDMA (Code Division Multiple Access). In 1982 GSM group is formed which laid the foundation of the modern wireless mobile networks. The demonstration of L band digital radio and the release of first GSM specification were the key events in wireless communication history in the beginning of the 19th century. The first GSM call was made in the year 1991 in Finland and six years later the IEEE 802.11 standard also known as Wi-Fi was created [9]. The 1G analog systems of 1980’s evolved into 2G digital technology in the 90’s and to third generation mobile communication which includes wireless multimedia services. The 3G mobile system evolved in 2002’s eliminating previous incompatibilities and became a truly global system. The forthcoming 4G mobile communication systems are projected to solve the still remaining problems of 3G systems and to provide a wide diversity of new services, from high quality voice to high definition video to high data rate wireless channels.

Milestones in the development of wireless communication are summarized in Table 1.3.
Table 1.3. Milestones in Communication [10-14]

<table>
<thead>
<tr>
<th>Year</th>
<th>Event</th>
</tr>
</thead>
<tbody>
<tr>
<td>1837</td>
<td>Morse demonstration of telegraph</td>
</tr>
<tr>
<td>1865</td>
<td>Prediction of electromagnetic wave propagation by Maxwell</td>
</tr>
<tr>
<td>1876</td>
<td>Alexander Graham Bell invented the Telephone</td>
</tr>
<tr>
<td>1887</td>
<td>The existence of Electromagnetic waves is verified by Heinrich Hertz.</td>
</tr>
<tr>
<td>1894</td>
<td>Wireless telegraphy by Marconi</td>
</tr>
<tr>
<td>1895</td>
<td>Jagadish Chandra Bose gave his first public demonstration of electromagnetic waves.</td>
</tr>
<tr>
<td>1901</td>
<td>First wireless transmission by Guglielmo Marconi with his transatlantic transmission.</td>
</tr>
<tr>
<td>1906</td>
<td>Radio broadcasting by Fessenden</td>
</tr>
<tr>
<td>1915</td>
<td>Direct telephone communications opened for service.</td>
</tr>
<tr>
<td>1921</td>
<td>Radio dispatch service initiated for police cars in Detroit, Michigan</td>
</tr>
<tr>
<td>1924</td>
<td>Directive Yagi-Uda antenna developed by Prof. Hidetsugu Yagi</td>
</tr>
<tr>
<td>1927</td>
<td>First television transmission.</td>
</tr>
<tr>
<td>1929</td>
<td>Microwave communication established by Andre G. Clavier</td>
</tr>
<tr>
<td>1933</td>
<td>Frequency Modulation techniques by Armstrong</td>
</tr>
<tr>
<td>1934</td>
<td>AM (Amplitude Modulation) mobile communications systems used by state and municipal forces in the U.S</td>
</tr>
<tr>
<td>1935</td>
<td>RADAR by Watson Watt, Radio astronomy by Janskey</td>
</tr>
<tr>
<td>1943</td>
<td>The first telephone line from Calcutta, India to Kunming, China.</td>
</tr>
<tr>
<td>1944</td>
<td>Telephone cable laid across the English channel</td>
</tr>
<tr>
<td>1946</td>
<td>Radiotelephone connections made to PSTN (Public-switched telephone network), 3.7-4.2 LOS link by AT&amp;T</td>
</tr>
<tr>
<td>1947</td>
<td>First Mobile phone demonstration</td>
</tr>
<tr>
<td>1953</td>
<td>Deep space communication proposed by John Pierce.</td>
</tr>
<tr>
<td>1957</td>
<td>Soviet Union launches Sputnik, humanity’s first artificial satellite.</td>
</tr>
<tr>
<td>1958</td>
<td>Invention of Integrated Circuit</td>
</tr>
<tr>
<td>1968</td>
<td>Development of the cellular telephony concept at Bell Laboratories.</td>
</tr>
<tr>
<td>1979</td>
<td>A 62,000 mile telecommunications system is implemented in Saudi Arabia</td>
</tr>
<tr>
<td>1980</td>
<td>1G first generation - only mobile voice service</td>
</tr>
<tr>
<td>1981</td>
<td>Beginning of first commercial cellular mobile communication</td>
</tr>
<tr>
<td>1982</td>
<td>Two way video teleconferencing service started</td>
</tr>
<tr>
<td>1986</td>
<td>Integrated Service Digital Network deployed</td>
</tr>
<tr>
<td>1990</td>
<td>2G-Second generation digital cellular deployed throughout the world.</td>
</tr>
<tr>
<td>1995</td>
<td>CDMA is introduced</td>
</tr>
<tr>
<td>2000</td>
<td>3G Standard is proposed.</td>
</tr>
<tr>
<td>2008</td>
<td>ITU-R organization specified the IMT-Advanced (International Mobile Telecommunications Advanced) requirements for 4G standards.</td>
</tr>
<tr>
<td>2010</td>
<td>Optical communication satellite</td>
</tr>
</tbody>
</table>
1.4 Wireless communication bands

Different frequency bands are allotted in communication systems for different applications. This avoids the congestion during the communication process. The different frequency bands allocated by the governing council for smooth running of communication process are given in the Table 1.4 with corresponding category of antenna.

Table 1.4. Wireless Communication [10-14]

<table>
<thead>
<tr>
<th>Name of the Wireless Communication Service</th>
<th>Allocated frequency band</th>
<th>Commonly used Antenna</th>
</tr>
</thead>
<tbody>
<tr>
<td>Digital Video Broadcasting (DVB-H)</td>
<td>470MHz-702MHz</td>
<td>Compact printed Antennas</td>
</tr>
<tr>
<td>Radio Frequency Identification (RFID)</td>
<td>865-868MHz, 2.446-2.454GHz</td>
<td>Loops, Folded-F, Patch and Monopole</td>
</tr>
<tr>
<td>Global System for Mobile (GSM 900)</td>
<td>890MHz-960MHz</td>
<td>Dipole, patch arrays and Monopoles.</td>
</tr>
<tr>
<td>Global Positioning System (GPS1400, GPS1575)</td>
<td>1227MHz-1575MHz, 1565MHz-1585MHz</td>
<td>Microstrip patch or bifilar helix</td>
</tr>
<tr>
<td>Digital Communication System (DCS 1800)</td>
<td>1710MHz-1880MHz</td>
<td></td>
</tr>
<tr>
<td>Personal Communication System (PCS 1900)</td>
<td>1850MHz-1990MHz</td>
<td>Dipole or patch arrays in base stations. Monopoles, sleeve dipoles and patch in mobile handset</td>
</tr>
<tr>
<td>International Mobile Telecommunication-2000 (3G IMT-2000)</td>
<td>1885MHz-2200MHz</td>
<td></td>
</tr>
<tr>
<td>Universal Mobile Telecommunication Systems (UMTS 2000)</td>
<td>1920MHz-2170MHz</td>
<td></td>
</tr>
<tr>
<td>Industrial, Scientific, Medical(ISM 2.4, ISM 5.2, ISM 5.8)</td>
<td>2400MHz-2484MHz, 5150MHz-5350MHz, 5725MHz-5825MHz</td>
<td></td>
</tr>
<tr>
<td>Ultra Wide Band (UWB) communication</td>
<td>3.1GHz-10.6GHz</td>
<td>Planar printed antennas, Horn Antennas</td>
</tr>
</tbody>
</table>
1.5 Mobile phone antennas

Antenna serves as one of the critical component in any wireless communication system. They act as electronic eyes and ears to the world. Antennas are the essential communication link to space, aircraft and ships. *IEEE Standard Definitions of Terms for Antennas* (IEEE std 145-1973)[15] defines the antenna or aerial as “a means for radiating or receiving radio waves”. In the last few years, the trend of the mobile phone technology was to decrease its size and weight. Due to this trend, the antenna used for mobile handheld devices became small and light weight. These low profile antennas have non-directional radiation pattern in the horizontal plane to provide maximum coverage. But there are challenges in the antenna’s performance during the interaction with head. Therefore, antennas used in mobile hand held devices for personal communications has been recognized as a crucial element.

Monopole antennas were the best choice for the automobiles and mobile devices because of its simplicity in design with excellent radiation characteristic for mobile equipment. The antenna used for the first phone was a half wavelength monopole antenna. Nowadays this viral part of wireless gadgets has endured renovation from a metallic rod to ceramic chip, reconfigurable, active and complicated smart antenna. It can also be seen that the built-in antennas are more preferable than the half-wavelength monopole antenna.

Since antenna is the fundamental part of any wireless systems, major advancement in antenna design is required for this explosive growth of wireless devices. These antennas are used in close proximity of biological tissues of the user, it should radiate enormous power towards the user. Modern communication system requires reliable communication with less radiation towards the user.
The antenna designer must consider the following electrical characteristics while designing a mobile handset antenna.

a) Operating frequency
b) Return loss
c) Bandwidth
d) Gain
e) Radiation pattern
f) Antenna tuning

In addition to size of the antenna, the RF interference towards the user has to be considered.

Some of the commonly used mobile antennas are discussed in this section.

1.5.1 Monopole

The radiator frequently used in communication is some form of thin wire arranged in a linear configuration. The fundamental mobile antenna is the quarter-wavelength monopole antenna. It has a simple structure as shown in Figure 1.3. Generally, a monopole antenna consists of a thin vertical wire mounted over the ground plane, whose bandwidth increases with increase in its diameter. For a half-wavelength monopole (length l=\(\lambda/2\)), the maximum current amplitude occurs around the center of the monopole therefore current amplitude around the feed point is small. However, for a quarter-wavelength monopole (l=\(\lambda/4\)) the maximum current amplitude occurs around the feed point [16]. When a monopole of length l= \(\lambda/4\) mounted above a ground plane, an image of length \(\lambda/4\) is formed and it behaves as \(\lambda/2\) dipole. Moreover, the 3/8 or 5/8 wavelengths monopole antennas have been employed for mobile terminals as they have the appropriate input impedance for matching the feed line. This antenna is also named as the “whip” antenna.
Introduction

Fig 1.3. (a) Normal wire monopole with ground plane (b) Planar monopole antenna

Planar monopole antennas are popular for their large bandwidth, moderate gain with nearly omni-directional radiation characteristics. They are very attractive for wireless communication applications due to its compact nature [17,18]. The major limitations of these antennas are the ground plane size and orientation of the radiator. The geometry of a wire monopole antenna with ground plane and planar monopole antenna are shown in fig1.3(a) and fig1.3(b) respectively.

1.5.2 Normal Mode Helical Antenna

Another type of antenna with omni-directional radiation pattern used in wireless devices is helical antenna. A helical antenna consists of a single conductor or multiple conductors wound into a helical shape. In the normal mode or broadside mode, the antenna acts similarly to an electrically short dipole or monopole with maximum radiation at right angles to the helix axis. In this mode, the dimensions of the helix are small compared with the wavelength and the radiation is maximum and parallel to the helix axis. [19]. A normal helix has been used as an effective means for reducing the length of thin wire
type (whip) antennas for personal and mobile communication systems. Figure 1.4 (a) and (b) shows the structure and photograph of a helical antenna.

![Image of helical antenna](image)

**(a)** Geometrical configuration **(b)** Photograph of a helix antenna

**1.5.3 Microstrip antenna**

The microstrip antennas have wide range of applications in wireless communication systems due to their great advantages. Microstrip structure consists of a thin sheet of low loss dielectric substrate. The radiating structure or antenna is printed on one side of the substrate and the other side is completely covered with a metal called ground. A typical microstrip element is illustrated in Fig. 1.5

![Image of microstrip antenna](image)

**Fig 1.5. Geometry of a conventional microstrip antenna excited with a microstrip line**
The advantages of microstrip antenna are

a) Low volume and light weight  
b) Low profile planar configuration  
c) Easy fabrication  
d) Easy integration with Microwave Integrated circuits.  
e) Supports both linear as well as circular polarization  
f) Capable of multiple frequency operations  
g) Mechanically robust when mounted on rigid surfaces

On the other hand they offer some disadvantages as

a) Narrow bandwidth  
b) Low gain  
c) Low polarization purity  
d) Excitation of surface waves

Microstrip antennas have very high antenna quality factor (Q). This large Q leads to narrow bandwidth and low efficiency. So the conventional microstrip patch is not a good candidate for the mobile wireless applications due to its inherent disadvantage of narrow bandwidth.

Different techniques are employed for reducing microstrip antenna size. Dielectric loading, top hat loading, and use of shorting pins are some of the techniques used to reduce the size and are summerised in Table 1.5 [20].
Table 1.5. Downsizing technique for microstrip antenna

<table>
<thead>
<tr>
<th>Downsizing technique</th>
<th>Geometrical (size reduction with respect to conventional resonant size)</th>
<th>Impedance bandwidth enhancement ratio</th>
<th>Radiation pattern (symmetry vs low cross polarization)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Material: high dielectric, slow wave etc</td>
<td>70%</td>
<td>2%</td>
<td>High</td>
</tr>
<tr>
<td>Shorting planes: Walls, pins etc</td>
<td>50%</td>
<td>5%</td>
<td>Low</td>
</tr>
<tr>
<td>Patch etching: slits, slots, notches, etc</td>
<td>50%</td>
<td>7%</td>
<td>Medium</td>
</tr>
<tr>
<td>Multilayered: fold, bend, stack, etc</td>
<td>60%</td>
<td>10%</td>
<td>high</td>
</tr>
</tbody>
</table>

1.5.4 Planar Inverted-L Antenna

The origin of the planar inverted-F Antenna can be traced all the way back to the Inverted-L Antenna (ILA). ILA consists of a short monopole as a vertical element and a horizontal wire element attached at the end of the monopole.

The ILA is basically a low profile antenna as the height of the vertical element is usually much less than a wavelength as shown in figure 1.6(a). The horizontal element is not necessarily very short, and usually has a length of about a quarter wavelength. The design is simple and can be easily manufactured on microwave substrates. Additionally, many of the electrical characteristics of the inverted-L are similar to those of the well understood short monopole. The ILA has low input impedance and its input impedance is equal to sum of the impedance of a short monopole and the impedance of the horizontal element closely placed to the ground plane [21]. Hence to increase the radiation impedance, another inverted-L element is attached to the end of the vertical element and this is how the inverted-F Antenna (IFA), as depicted in Fig. 1.6(b), is formed from the ILA.
Fig. 1.6. Structure of (a) Inverted-L antenna (b) Inverted F antenna

This adjustment can be vital because the input impedance of an IFA can be set to have an appropriate value to match the circuit, without using any additional circuit between the antenna and the input. For this reason, the IFA, rather than the ILA, has been used practically and applied often to moving bodies such as rockets and aircraft due to its low profile structure. In addition to the above-mentioned features, its performance with two polarizations would be useful for urban environments. This is especially true for application on mobile equipment like the hand-held transceiver.

1.5.5 Planar Inverted-F Antenna (PIFA)

The Planar Inverted F Antenna (PIFA) is well known as terminal antenna. The small size and low profile nature of the PIFA, make it an excellent choice on portable equipment. These antennas offer reduced size over traditional microstrip antennas because it resonate at quarter wave length. PIFA consists of a top patch, ground plane, a feed wire and a shorting mechanism which short top patch to the ground. Typical geometry of a PIFA is shown in figure 1.7. The PILA/PIFA can be considered as a combination of the inverted-L/F (ILA/IFA) antenna and the short circuited rectangular microstrip antenna (SCMSA). The shorting mechanism makes it a quarter wave resonator and reduces the electrical length. Bandwidth of the antenna can be enhanced by increasing the
height, the width of the shorting plate and width of the radiating patch. [22].
Stacking and insertion of slits are included in PIFA’s to create multiband operation [23-24].
Table 1.6 summerizes the effect of different PIFA design parameters (height, width, length, location of feed and shorting pin / wall and size of the ground plane) and its radiation characteristics.

Table 1.6. The effect of PIFA parameters on its characteristics

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Effect</th>
</tr>
</thead>
<tbody>
<tr>
<td>Height</td>
<td>Control bandwidth</td>
</tr>
<tr>
<td>Width</td>
<td>Impedance matching</td>
</tr>
<tr>
<td>Length</td>
<td>Increase inductance of the antenna and determine resonance frequency</td>
</tr>
<tr>
<td>Width of short strip</td>
<td>Affect on the antiresonance and increase bandwidth</td>
</tr>
<tr>
<td>Feed position from short strip</td>
<td>Affect on resonance frequency and bandwidth</td>
</tr>
</tbody>
</table>

![Fig.1.7. Structure of Planar Inverted-F Antenna](image)

The mechanical stability, the requirement of precise position between feed pin connection and short circuited plate to obtain input impedance of 50 ohm, is another problem in the practical application of PIFAs.
1.5.6 Metamaterial based antenna

Recently there has been a growing interest in metamaterials with negative permittivity and permeability as candidates for design of novel microwave devices. An electromagnetic wave propagating through such material has a Poynting vector anti-parallel with its phase-velocity vector as demonstrated theoretically by Veselago [25]. Such materials have been termed by several names including “left handed” [26]–[29], “negative refractive index” [30], “negative phase velocity” [31] and “backward wave (BW) media” [32], [33]. Such materials have been realized in the microwave range by Smith et al. [25], [26]. An application of Negative Index Material (NIM) to increase the power radiated from electrically small antennas has been suggested by Ziolkowski and Kipple [34]. Moreover, Engheta recently proposed [35] the use of NIMs to design thin sub-wavelength cavity resonators.

This interest has come from the demonstration that specific sub-wavelength structures, that is, structures having electrically small dimensions compared to the wavelength, can exhibit effective permeability which can be tuned to negative values over a finite frequency range. A negative permittivity medium can be obtained by arranging thin metallic wires periodically [36], [37]. The continuous wire structure behaves like a high-pass filter which means that the effective permittivity will take negative values below the plasma frequency [36]. However, for discontinuous wire structures, the negative permittivity region does not extend to zero frequency, and there appears a stopband around the resonance frequency. In 1999, Pendry et al. have suggested that an array of Split Ring Resonators (SRRs) might exhibit a negative effective magnetic permeability for frequencies close to the resonance frequency of these structures [27]. By combining these SRRs and thin wires, Smith et al. reported the first experimental demonstration of left-handed metamaterials. [29].
1.5.7 Electronic Band gap structure antennas

The Electromagnetic Band Gap (EBG) structure, also referred to as a Photonic Band Gap (PBG) structure or a high-impedance surface, has attracted the scientists recently. Extensive studies in applying its band gap phenomena for practical uses both in the optical domain and microwave & millimeter wave areas has been reported. An EBG structure is a periodic, normally dielectric structure with certain geometry and dimensions, exhibiting in its spectral behavior so called band gap, a range of frequencies, at which electromagnetic waves are not allowed to propagate in the structure. The EBGs have already been widely exploited for antenna related applications. They were used as substrates, superstrates and coatings for shaping and improving the radiation characteristics of antennas of different types [38]-[40]. In particular, their ability of confining and guiding electromagnetic energy has opened up new applications and solutions in microwave and optical devices design. These novel concepts can be realized in EBGs with cavities or defects [41] which can function as resonators, waveguides. Point defects in EBGs were applied to antennas in order to achieve larger directivities and higher efficiencies [42].

1.6 Analysis of antennas

The art of computation of electromagnetic problems has grown exponentially during the last three decades due to the availability of powerful computer resources. Computational ElectroMagnetics (CEM) an important field in the design and modeling of communication systems, medical imaging, radar, antenna and cellular handset antenna. CEM typically solves the electromagnetic problem of computing the E (Electric) and H (Magnetic) fields across its domain. System modeling involving electromagnetic wave interactions based on frequency domain techniques [43-44] and integral equation method [45-46]
or time domain techniques such as Finite Difference Time Domain method (FDTD). Frequency domain numerical solutions are achieved by approximating the relevant differential or integral equations and solving large matrix equations. But differential equation solutions such as Finite Difference Method (FDM) and Finite Element method (FEM) are the easiest techniques to implement. The family of EM analysis techniques for the solution of Maxwell’s equations is shown in the figure 1.8.

![EM Analysis Techniques Based on Solving Maxwell's Equations](image)

**Fig.1.8. Family of EM analysis techniques**

Operating principle and design characteristics of an antenna can be studied using antenna analysis. Target geometry, electrical parameter and excitation used in the structure should be defined prior to the antenna analysis. The analysis of a microwave circuit can be considered as shown in figure.1.9.
Transmission line model, cavity model and multi port network model are used for the analysis. Full wave method for the analysis of an antenna, solves Maxwell’s equation subject to boundary conditions at the interface. Different methods for the analysis of antennas are described in the following sections.

1.6.1 Transmission Line Matrix method (TLM)

The transmission line matrix method was originally developed by Johns and Beurle [47]. It replaces the structure by a mesh, either 2D or 3D. The nodes of the grid are interconnected by virtual transmission lines. Excitation at the source nodes propagate to adjacent nodes through the transmission lines at each time step. Generally, dielectric loading is accomplished by loading nodes with reactive stubs, whose characteristics impedance is appropriate for the amount of loading desired. Lossy media can be modeled by introducing loss into the transmission line equations or by loading the nodes with lossy stubs. Absorbing boundaries are constructed in TLM meshes by terminating each boundary node transmission line with its characteristics impedance. Analysis is performed in the time domain. Complex, nonlinear materials are readily modeled, impulse responses and time-domain behavior of the systems are determined explicitly. The technique is suitable for implementation on massively parallel machines.
But, voluminous problems using fine grids require excessive amounts of computation. TLM method shares the advantages and disadvantages of the FDTD method, and discussed later.

### 1.6.2 Method of Moments (MoM)

The use of MoM for solving electromagnetic structures became popular by the work of Richmond in 1965 and Harrington in 1967[48-49]. MoM is a method of solving a differential equation or an integral equation numerically by transforming the equation into simultaneous equations. Regarding antenna analysis integral equation for electric field on the surface of the conductor is usually used to obtain the surface current on the antenna. The substrate and ground plane are assumed to be infinite in lateral dimensions and formulation of the problem is based on rigorously enforcing the boundary condition. In Electric Field Integral Equation (EFIE) the boundary condition is applied to the total tangential electric field where as in Magnetic Field Integral Equation (MFIE) boundary condition is expressed in terms of magnetic field. Mixed Potential Integral Equations (MPIE) has both scalar and vector potentials in its formulation [50]. The integral equation is then solved either in spectral domain or spatial domain by taking appropriate transformations. The procedure for applying MoM to solve an electromagnetic problem involves four steps:

- Derivation of the appropriate integral equation (IE)
- Conversion (discretization) of the IE into a matrix equation using basis (or expansions) functions and weighting (or testing) functions.
- Evaluation of the matrix elements
- Solving the matrix equation and obtaining the parameters of interest.
To solve Integral Equation it is discretised into set of linear equations by means of moment method. By solving the matrix equation the surface current on the patch conductor can be obtained which is then used for extracting the radiation pattern, polarization, directivity etc. MoM depends upon expanding the unknown quantity in the equation in terms of known entire domain or sub domain basis functions with unknown coefficients. The selection of basis function is very important step in the numerical solution since they have the ability to accurately represent and resemble the anticipated unknown function while minimizing computational effort [51-53]. The popularly used basis functions are piece wise sinusoidal, pulse basis and roof top basis functions. A set of equations is generated by enforcing the boundary conditions with a suitable set of testing functions. This results in a matrix whose order is proportional to the number of segments on which the current distribution is represented. The solution to the problem is found by inverting this matrix.

1.6.3 Finite Element Method (FEM)

The mathematical concept of FEM was provided by Courant in 1943[54]. This concept was not in use to EM problems until 1968. The FEM is used for finding the approximate solution of Partial Differential Equations (PDEs) and Integral Equations (IEs). FEM uses a volumetric approach which requires the entire volume of the configuration to be meshed as opposed to surface integral techniques, which require only the surfaces to be meshed. The properties of the neighboring mesh elements are entirely different. In general, the FEM is a good choice for solving PDEs over complex domains or when the desired precision varies over the entire domain. However, unbounded radiation problems are not handled as effectively as MoM. It uses both tetrahedral and prismatic elements to mesh the structure.
The FE analysis of any problem involves basically four steps [55]:

a) Discretizing the solution region into a finite number of sub-regions or elements;

b) Deriving governing equations for a typical element;

c) Assembling of all elements in the solution region; and

d) Solving the system of equations obtained.

The major weakness of FEM is that it is relatively difficult to model open configurations. However, in finite element methods, the electrical and geometric properties of each element can be defined independently. This permits the problem to be set up with a large number of small elements in regions of complex geometry and fewer but large elements in relatively open regions. Thus it is possible to model configurations that have complicated geometries and many arbitrarily shaped dielectric regions in a relatively efficient manner.

1.6.4 Finite Difference Time Domain (FDTD) method

The Finite Difference Time Domain (FDTD) technique is arguably the most popular numerical method for the solution of problem in electromagnetic. First proposed K.S.Yee in 1966 [56] and refined and reinvented by Taflove [57] in the 1970’s. The FDTD method belongs in the general class of differential time-domain numerical modeling methods. Maxwell’s (differential form) equations are simply modified to central-difference equations, discretised, and implemented in software. The electric field is solved at a given instant in time. Then the magnetic field is solved at the next instant in time, and the process is repeated over and over again. This method permits the modelling of electromagnetic wave interactions with a level of detail as high as that of the Method of Moments. Each field component is
updated with the knowledge of the immediately adjacent field components calculated one-half time step earlier. Therefore, overall computer storage and running time requirements for FDTD are linearly proportional to the number of field unknowns in the finite volume of space being modelled. FDTD method is well known in the field of Computational Electromagnetics. FDTD is a time domain technique, and when a time domain pulse (Gaussian pulse) is used as the source pulse, then a wide frequency range is solved with only one simulation. The displacement between electric and magnetic field components in Yee’s FDTD, is modified by Chen et al. [36]. This new formulation is exactly equivalent to the symmetric condensed node model used in the TLM method. Thus the TLM algorithm can be formulated in FDTD form and vice versa. However, both algorithms have their unique advantages. FDTD is a very versatile modeling technique and parameters are directly introduced, while the modeling of boundaries and the partitioning of the solution region can be done easily in TLM. The selection of algorithm for numerical investigation is completely user dependent.

1.7 Motivation of present research

The thesis is the outcome of the experimental and simulation investigations on mobile antennas with less radiation hazards. In the last two decades, the use of the cellular phones has become the most popular mode of communication across the globe and it is the most common media used for making connections with different people. Due to the rapid growth in the use of mobile phones and other wireless communication systems, there is a great concern about the harmful radiation from these 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. The reduction of power absorbed by the user reduces potential health hazards. Protect users against radiations
from cellular phones can be achieved in two ways either by reducing the emitted power of electromagnetic radiations towards the user to a minimum value or by limiting the time of exposure to such fields. The latter condition depends largely on the user. The former condition of cutting down the amount of radiation power absorbed by the user's head can be met by modifying the omnidirectional radiation pattern of the antennas used in cellular phones. The near field characteristics of these antennas are also studied to determine the interaction between the human head with antennas.

The main objectives of the thesis are

- The experimental and simulation investigations on the possibility of resonance of a coplanar wave guide fed monopole antenna by varying the signal strip and ground plane dimension.
- Create mobile antenna by modifying the radiation characteristics of a CPW fed monopole antenna with less radiation towards a single quadrant (users head) using a parasitic element.
- Study the radiation characteristics of antenna with different parasitic elements using both simulation and experiment.
- Modify an Open Ended planar Transmission line into a ground folded transmission line.
- Design a more compact antenna to steer the null using folding technique.
- Create a ground folded antenna with modified radiation characteristic by the introduction of a single strip as a parasitic element without affecting the compactness.
Study the experimental and simulation investigations on near field radiation characteristics.

1.8 Thesis organization

The thesis comprises of six chapters.

Chapter 1 describes an overview of antenna research, state of the art of technologies in antennas, radiation effects due to such antennas and finally the motivation of present research.

Chapter 2 illustrate the antenna fabrication method and the experimental facilities utilized. The measurement methods employed to study the characteristics of the antenna in the near and far field are presented in this chapter. It also provides a thorough review of planar antennas and mobile antenna with reduced Specific Absorption Rate.

Chapter 3 deals with the development of a mobile antenna with less radiation towards human head. Figure of eight radiation characteristics of the coplanar wave guide fed monopole antenna is modified to produce a pattern with a single null. This modification in radiation characteristics is studied for different parasitic structures. The design criteria and parametric analysis are also presented.

The development of an antenna by modifying the ground plane to change the direction of null is discussed in chapter 4. The modification of an Open Ended Coplanar Waveguide Transmission line into an effective open ended ground plane folded transmission line is elaborately described in this chapter. A ground folded mobile antenna operating in the GSM 1800 band with radiation characteristics suitable for mobile handset is also elaborately presented and discussed.
The near field radiation characteristics of the proposed antennas are studied in detail in Chapter 5. In this chapter both the simulation and measured results in the near field region of the antenna are discussed. Antenna characteristic and Specific Absorption Rate (SAR) with head model are also presented in this chapter.

Chapter 6 describes conclusions of the thesis. The scope for future works is also described.

Other major works carried out during the research period is given in appendix.

Appendix 1 gives the design of a compact asymmetric coplanar strip fed antenna for wide band applications.

Appendix 2 gives the development of a compact CSRR based patch antenna for wireless applications.
Refernces


[17] Antenna system guide, NIJ Guide 202-00, pp 17-26


Introduction


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