Chapter 1

Introduction

The demand for wireless services such as wireless local area network (WLAN), wireless personal area networks (WPAN), wireless telemetry, telemedicine, cellular network and wireless sensor network (WSN) is growing over the past decade. New generation of wireless radio system aims to provide flexible data rates including high, medium and low data rates for a wide variety of applications like data, video, ranging etc. to as many mobile users as possible. The explosive growth of the wireless market is unlikely to abate. Since more and more devices are going wireless, accommodating the demand for high capacity and data rate within the limited bandwidth is a challenging task. It is essential that current and future wireless technologies coexist with devices operating at various frequency bands.

1.1.1 UWB HISTORY

Ultra Wideband (UWB) is a promising solution to this problem that can coexist with other licensed and unlicensed narrowband systems. USA, the first country to legalize UWB for commercial use allowed the unlicensed use of UWB devices subject to the emission constraints. Federal Communication Commission (FCC), USA, released the First Report and Order on Feb 14, 2002. The order is for the UWB systems in the range from 22 GHz – 29 GHz, 3.1 GHz – 10.6 GHz, and below 900 MHz depending on application. However, this technology is not anything new, considering that it was employed by Marconi in 1901 to transmit Morse code sequences across the Atlantic Ocean using spark gap radio transmitters. But, the benefit of large bandwidth and capability of implementing multi user system provided by electromagnetic pulses were never considered. Nearly 50 years after Marconi, modern pulse based transmission gained momentum in military applications in the form of impulse radars [Kshetrimayum (2009)]. The research in time domain electromagnetics in 1960’s which described the transient behavior of few types of microwave networks resulted in the birth of UWB technology. From 1960s to 1990s this technology was restricted to defense applications
under high secure communication. In 1978 Benett and Ross wrote a summary of time domain electromagnetics. They also submitted the landmark patent in UWB communications in 1973. The term Ultra Wideband appeared in 1989 in a publication of department of defense in the United States and the first patent with the exact term ‘UWB Antenna’ was filed on behalf of Hughes in 1993. Thus the interest in UWB was revived in 1990s. By this time UWB theory had undergone thirty years of development. In 2002, the interest for UWB system was rejuvenated by the allocation of 500 MHz or a bandwidth which is at least 20% of center frequency by FCC. To avoid inadvertent jamming of existing systems such as GPS satellite signals, the lowest band edge for UWB communication was set at 3.1 GHz with highest at 10.6 GHz as illustrated in Figure 1.1. It also placed restriction on the emission level. The emission must be below -41.3dBm/MHz for the unlicensed indoor UWB wireless communication systems. FCCs indoor and outdoor emission mask is shown in Figure 1.2.

![Figure 1.1 Spectrum of different wireless communication](image-url)
1.1.2 UWB ADVANTAGES

The key benefits of UWB over narrowband technology are high data rate, low equipment cost, multipath immunity, ranging and communication. Data rate of existing UWB systems is 500 Mbps within 10 m. High data rate characteristic of UWB is evident from Shannon-Hartley criteria as given in the equation below,

\[ C = B \log_2 \left( 1 + \frac{S}{N} \right) \] (1.1)

Where,

- \( C \) maximum channel capacity (bps)
- \( B \) channel bandwidth (Hz)
- \( S \) signal power (W)
- \( N \) noise power (W)
From the equation, it is evident that the channel capacity can be improved either by increasing bandwidth, signal power or by decreasing noise power. It is easier to increase bandwidth where the variation is linear rather than the logarithmic variation of signal to noise ratio. Also, due to the availability of large bandwidth of UWB, tradeoff between bandwidth and SNR is easier. Low equipment cost is possible due to the carrierless transmission of UWB which eliminates the need for complex RF components making the system low cost and less complex [Schantz (2003)]. Furthermore, UWB system is immune to detection and interception due to the low emission level [Gavami, (2008)]. High precision ranging is possible due to the inherent high delay resolution and ability to penetrate obstacles which finds application in many different fields especially in indoor and dense urban environments where signal is unavailable and localization becomes a more challenging problem [Chong, et al (2006)].

1.1.3 UWB COMMUNICATION

UWB transmission may be pulse based: impulse radio UWB (IR-UWB) [Xu et al (2008)], the direct sequence UWB (DS-UWB) [Parihar, et al (2007)] or carrier based: multiband orthogonal frequency division multiplexing (MB-OFDM) [Chen et al (2007), Xiao, (2003)]. In IR-UWB information transmission is by changing the amplitude, position, polarity or shape of the pulses which occupy the entire frequency band. It is suitable for low data rate (LDR) system application like RFID, asset/inventory control, equipment tracking etc. owing to the low duty-cycle [Tommy et al (2005)]. DS-UWB uses short duration pulses for transmission and is suitable for medium to high data rate transmission with high duty cycle. The DS-UWB provides ultra high rate, low cost and low power solutions for handheld devices. MB-OFDM can be accessed by transmitting continuous OFDM symbol and altering the frequency in accordance to time frequency hop pattern [Xu et al (2008)]. This system is suitable for high data rate (HDR) and short range applications. A comparison of IR-DS UWB and MB-UWB is provided in Table.1.1 and spectrum allocation is shown in Figure 1.3. DS-UWB is divided into two frequency sub-bands, whereas MB-UWB spectrum is divided into fourteen bands each with 528 MHz bandwidth.
Figure 1.3 Frequency spectrum of MB-UWB

Table 1.1 Comparison of different UWB techniques for WPAN

<table>
<thead>
<tr>
<th>Specification</th>
<th>MB-OFDM</th>
<th>DS-UWB</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of frequency sub-band</td>
<td>3 Mandatory</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>11 optional</td>
<td></td>
</tr>
<tr>
<td>Frequency band of each group</td>
<td>3.168 - 4.752 GHz</td>
<td>3.1 - 4.85 GHz</td>
</tr>
<tr>
<td></td>
<td>4.752 - 6.336 GHz</td>
<td></td>
</tr>
<tr>
<td></td>
<td>6.336 - 7.920 GHz</td>
<td>6.2 - 9.75 GHz</td>
</tr>
<tr>
<td></td>
<td>7.920 - 9.504 GHz</td>
<td></td>
</tr>
<tr>
<td></td>
<td>9.504 - 10.56 GHz</td>
<td></td>
</tr>
<tr>
<td>Bandwidth of sub-band parameter</td>
<td>528 MHz</td>
<td>3.25 GHz</td>
</tr>
<tr>
<td></td>
<td>1.75 GHz</td>
<td></td>
</tr>
</tbody>
</table>
1.1.4 UWB APPLICATION

According to the released regulation, UWB technology based on transmitting ultra short pulses with duration of only a few nanoseconds or less has received great attention in various fields for short distance (< 10 m) wireless communication. Due to its unlicensed operation and low power transmission, UWB can coexist with other wireless devices and its low cost, low power transceiver circuitry makes it a good candidate for short to medium range wireless systems such as WSNs and WPANs. The controlled transmitted power of UWB devices affects the other narrowband system only minimally. Hence UWB has emerged as one of the hot topics for the wireless world including wireless home networking, high density use in office buildings, business cores, UWB wireless mouse, keyboard, wireless speakers, wireless USB and wireless body area network. Figure 1.4 gives a comprehensive picture of UWB applications.

![Figure 1.4 UWB indoor applications](source: IST pulsers)
Antennas being an important component in any wireless communication, UWB applications demand that they satisfy certain specifications:

- cover large bandwidth.
- display consistent radiation pattern throughout the band
- prevent interference with the existing wireless networks such as WiMAX (3.3 - 3.7 GHz) and WLAN (5.15 - 5.35 GHz and 5.725 - 5.825 GHz) band.
- remain low cost and of a size small enough to be integrated into handheld/portable devices.

In this thesis the research focus is on the design of printed antennas to satisfy the above criteria, especially on printed monopole and slot antennas. The performance of each antenna is investigated to assess its suitability for UWB applications.

Antenna requirement for UWB also varies depending on the type of transmission. A detailed review on different types of antennas for wide band application is given in Chapter 2.

1.2 OBJECTIVE

Consumers demand high speed wireless connectivity for connecting PCs, PDR and HDTV. Today’s communication market is also moving towards high speed wireless connectivity to satisfy the demands. It is imperative therefore that suitable wide band, low profile and low cost antennas are designed and its performance constantly improved upon. The main objectives of this thesis are:

- To design and implement antennas to provide ultra wide bandwidth.
- To achieve WiMAX/WLAN band notch characteristics.
- To investigate the performance of the antennas that is fabricated on printed photolithography technique.
- To demonstrate both numerically and experimentally that the proposed antennas are suitable for UWB technology.
1.3 METHODOLOGY

The thesis objective is achieved initially by designing the antenna theoretically. Wide bandwidth is achieved by either introducing steps in the radiator or by exciting slots on the patch. The band-notch characteristic is obtained by etching half wavelength resonant slot either in the radiator or in the ground plane. The reflection coefficient characteristics and radiation pattern of the designed antenna is analyzed using CST simulation tool. After having obtained the preliminary results, it is fabricated and the performance is validated using network analyzer and anechoic chamber measurements.

1.4 RESEARCH CONTRIBUTION

The principal contributions made in this thesis are:

- Compact printed tapered UWB antenna is designed with a size reduction of 40%.
- Step monopole antenna with sharp band edge frequency.
- Pentagonal microstrip antenna with interlocked pentagon slots for dual band notch characteristics.
- CPW fed slot antenna with ultra wideband characteristics.

1.5 ORGANIZATION OF THE THESIS

The thesis is organized as follows:

Chapter 1 gives the introduction to the thesis, research objective and methodology.

In Chapter 2 Background information on antennas, literature review, and concepts related to UWB antenna requirements are summarized.

Design of three novel printed planar monopole antennas is presented in Chapter 3. First, a compact microstrip line-fed printed tapered ultra wideband planar monopole antenna is designed. Additional resonances are created by cutting slots in the ground plane. Second, a step monopole antenna with sharp band edge frequency is designed. Sharp band edge is
obtained by inserting a rectangular slot on the ground plane. The third is a microstrip line-fed UWB pentagonal antenna. Band notch characteristics is achieved by either embedding a half wavelength C-shaped slot on the radiator or by etching a split ring slot on the radiating patch and a pair of inverted S-shaped slot in the partial ground plane. Working principle for ultrawide bandwidth is studied through H-field analysis of an arrow shaped antenna.

In Chapter 4 design of a coplanar waveguide fed slot antenna with UWB characteristics is presented. Ultra wide bandwidth is achieved by exciting the rectangular slot antenna with C-shaped stub. Band-notch characteristic is achieved by embedding a rectangular slot on the ground plane.

Chapter 5 condenses and concludes the research that has been carried out together with the scope of future work.