CHAPTER 1

INTRODUCTION

1.1 GENERAL

The recent rapid growth in technology and the successful commercial deployment of wireless communications affect our daily lives. The transition from analog to digital cellular communications, the rise of third and fourth generation radio systems and the replacement of wired connections with Wi-Fi and Bluetooth are enabling consumers to access a wide range of information from anywhere and at any time. As the consumers demand for higher capacity, faster service and more secure wireless connections increases, new enhanced technologies have to find their place in the overcrowded and scarce radio frequency (RF) spectrum. This is because every radio technology is allocated to a specific part of the spectrum; for example, the signals for TVs, radios, cell phones and so on are sent on different frequencies to avoid interference to each other. As a result, the constraints on the availability of the RF spectrum become more and more strict with the introduction of new radio services. Ultra-wideband (UWB) technology offers a promising solution to the RF spectrum drought by allowing new services to coexist with current radio systems with minimal or no interference. This coexistence brings the advantage of avoiding the expensive spectrum licensing fees that providers of all other radio services must pay. Ultra-wideband (UWB) became popular after the Federal Communications Commission (FCC) in the USA allowed the unlicensed use of UWB devices in February 2002 subject to emission constraints. Its low cost and low power
transceiver circuitry makes it a good candidate for short to medium-range wireless systems such as WSNs and wireless personal area networks (WPANs). One of the most promising aspects of UWB radios is their potential for high precision localization. Due to their large bandwidths, UWB receivers can resolve individual multipath components (MPCs). Therefore, they are capable of accurately estimating the arrival time of the first signal path. This implies that the distance between a wireless transmitter and a receiver can be accurately determined, yielding high localization accuracy. Such unique aspects of UWB make it an attractive technology for diverse communications, ranging and radar applications such as robotics, emergency support, intelligent ambient sensing, health care, asset tracking and medical imaging.

1.2 CHALLENGES IN PRINTED ANTENNA DESIGN

The advancement of modern wireless communication systems integrates many applications such as WLAN, Bluetooth and UWB to a single handheld communication device. One of the challenges for the implementation of UWB systems is the development of a suitable or optimal antenna. In UWB antenna design, both the frequency and time domain responses should be taken into account. The frequency domain response includes impedance, radiation and transmission. The impedance bandwidth is measured in terms of return loss or voltage standing wave ratio (VSWR). Usually, the return loss should be less than -10 dB or VSWR < 2:1. An antenna with an impedance bandwidth narrower than the operating bandwidth tailors the spectrum of transmitted and received signals, acting as a band pass filter in the frequency domain and reshapes the radiated or received pulses in the time domain.

Nowadays, the multifunctional communication systems such as 2.4 GHz WLAN and UWB systems demand small printed antennas with
consistent impedance bandwidth, radiation pattern, polarization and time
domain characteristics over the wide frequency band. Accordingly, design of
simple printed antenna with desired characteristics over the wide bandwidth is
necessary.

The second aspect is the impact of narrowband interference on
UWB receivers. Specifically, the UWB frequency band overlaps with that of
IEEE802.11a wireless LANs. In order to avoid this interference, the antenna
should show notch band characteristics over the IEEE802.11a WLAN bands.

Apart from this, ground plane of the printed antenna plays an
important role in the design. The ground plane is generally considered to be
the return path for the antenna current. In the case of microstrip fed planar
antennas or microstrip antennas, etching is required on both sides of the
dielectric substrate. Hence, the characteristics of small antennas mounted on
the handheld devices get affected by the dimensions of the terminal chassis,
due to the existence of radiating surface currents on the terminal ground plane
induced by the antenna element. Therefore, it is necessary to design an
antenna which overcomes all the above limitations.

1.3 OBJECTIVES

The objectives of this research work are

- To design, simulate, fabricate and experimentally study simple
  planar antenna structure to achieve wide band characteristics for
  UWB applications.

- To design, simulate, fabricate and experimentally test compact
  printed antennas with appropriate feeding and matching
  techniques which improve the impedance bandwidth for 2.4
  GHz WLAN and UWB operations.
To explore 5 GHz notch band function for the proposed 2.4 GHz WLAN and UWB antennas.

To experimentally verify the consistency of radiation and performance characteristics such as impedance bandwidth, radiation patterns, gain, transfer function and group delays of the proposed 2.4 GHz WLAN and UWB antennas with 5 GHz notch band function.

In order to achieve all these objectives, a comprehensive literature review is done to identify an appropriate printed antenna that satisfies the design consideration for 2.4 GHz WLAN and UWB operations with notch band characteristics.

1.4 LITERATURE REVIEW

In practical UWB/WLAN applications, the antennas that can be directly printed onto printed circuit boards (PCBs) are the most promising candidates. Such a PCB antenna has a low profile, low manufacturing cost and can easily be integrated with other parts of monolithic microwave integrated circuit (MMIC) for a transceiver or any other UWB/WLAN systems. The proposed commercial UWB radio concept with its frequency from 3.1 GHz to 10.6 GHz differs significantly from traditional wideband short-pulse applications, such as radar. Furthermore, UWB/WLAN antennas need different requirements due to its applications such as portable electronics and mobile communications. Therefore, the conventional UWB antennas are not suitable. Many kinds of the new antenna are proposed to satisfy different requirements such as size, gain and radiation patterns. Also, several bandwidth enhancement techniques have been reported to improve the impedance bandwidth of these antennas.
Planar monopole antennas have been investigated for broadband applications for many years. These antennas feature broad bandwidth, small size and low cost. Many kinds of the planar monopole UWB antennas have been proposed so far. Tu Zhen et al (2004) introduced ultra wideband dipole antenna concept and developed the UWB dipole antenna from the cone antenna. Qu et al (2005) introduced the quadrate bowtie antenna concept and improved its property like better return loss in high frequency, smaller size and high gain, by inserting round corners on the rectangular bowtie antenna. Behdad et al (2004) have improved the performance of the folded bowtie antenna by adding a shorting loop to the outside of a bowtie antenna. The optimized antenna has 8.5:1 impedance bandwidth and consistent radiation parameters over a 4.5:1 frequency range. Also, it has excellent polarization purity over the entire 8.5:1 frequency range. Kwon et al (2005) and Nakasuwan et al (2008) developed new bowtie antennas to enhance the bandwidth. The bandwidth of the antennas achieves more than the 3 GHz-10.6 GHz needed for UWB communication systems. These are the good examples of the UWB bowtie antenna.

The planar monopole antennas for UWB systems can further be sorted by feeding methods such as microstrip feeding and coplanar waveguide feeding. There are four types of the patch shape in the microstrip fed UWB antennas such as rectangular, triangular, circular and elliptical. The main features of these shapes are their simple geometry and construction. Many such monopole antennas have been explored numerically and experimentally and have been shown to exhibit very wide bandwidth (Schantz et al 2003; Ammann et al 2003 and Liang et al 2004). Choi et al (2004a) proposed a new microstrip fed ultra-wideband antenna. In this antenna, three techniques are used to achieve wide bandwidth: the use of (i) two steps, (ii) a partial ground plane and (iii) a single slot on the patch, which leads to a good impedance matching. Jung et al (2005) introduced a small wideband microstrip monopole
antenna which consists of a rectangular patch with two notches at the two lower corners of the patch and a truncated ground plane with the notch structure. The triangular patch and its modified structures of microstrip fed UWB antenna are also introduced (Lin et al 2005; Verbiest et al 2006a; Cho et al 2006). The structure proposed by Lin et al (2005) is based on the triangular monopole antenna. It consists of a tapered radiating element fed by a microstrip line. The VSWR of the antenna with the optimized constructive parameters is less than 3 from 4 GHz to 10 GHz. Verbiest et al (2006a) developed further this antenna by inserting a slot in the patered radiating element and in the ground plane, which yields a wideband property with a relative good matching. The broad bandwidth was also achieved by triangular shaped patch with the staircases instead of the bowtie patch, a modified ground plane and two slits near the 50 Ω microstrip line (Cho et al 2006). Su et al (2004) developed square planar monopole antenna for IEEE 802.16a operations. The circular and elliptical patch antennas fed by the microstrip line are good candidates for UWB antenna design (Liang et al 2004a and Liang et al 2005a). A circular monopole antenna yields a broader bandwidth as compared to a rectangular monopole antenna with similar dimensions. The circular monopole is more gradually bent away from the ground plane than the rectangular monopole. This provides smooth transition between the radiator and feed line resulting in a wider bandwidth (Azenui 2007). The circular disc monopole UWB antenna is miniaturized by using tapered feeding line and improved ground shape, while the performance of the antenna is maintained (Zhang et al 2008a). The elliptical patch caused similar effect of beveling the radiating element and cutting slot in the ground plane provides an ultra-wideband impedance bandwidth (Huang et al 2005).

Instead of microstrip fed monopole antennas, many patch shapes for UWB antenna fed by coplanar waveguide (CPW) feeding method have been proposed (Gupta et al 2005; Liang et al 2005b; Yang et al 2004;
Tran et al 2007; Liang et al 2005c; Shrivastava et al 2008; Liang et al 2006; Wang et al 2004; Kim et al 2005). The rectangular and circular patch in (Gupta et al 2005; Liang et al 2005b) are well known for UWB antenna and Yang et al (2004a) showed the modified shapes. Tran et al (2007) and Shrivastava et al (2008) are designed UWB antennas using a modified ground plane which has three functions: (1) a ground plane for the monopole and CPW (2) radiating element and (3) component to form the distributed matching network with the monopole. Kim et al (2005) designed the antenna for UWB systems by using FDTD and genetic algorithm.

The planar monopole antennas are promising antennas for UWB applications (Liang et al 2006a, Agrawall et al 1998). But these antennas suffer from high cross polarization level. This is because of large lateral size and asymmetric geometry of the planar radiator. There are several good UWB planar antenna designs including planar half disk antenna (Yang et al 2004b) and metal plate antenna (Wang et al 2004). The critical issue in this UWB antenna design is the size of the antenna for portable devices.

Slot antennas are currently under consideration for use in ultra-wideband (UWB) systems. This is because of its attractive advantages such as low profile, light weight, ease of fabrication and wide frequency bandwidth. This type of antenna has been realized by either microstrip line or CPW feeding structures. Different configurations of printed slot antennas have been proposed for narrow band and wideband applications. These are Bow-tie slot antenna (Soliman et al 1999a), Cusp antenna (Soliman et al 1999b), rectangle (Jang et al 2000), (Chiou et al 2003), (Liu et al 2004) and (Kookestani et al 2010), multi resonant single element (Behdad et al 2004, 2005), triangle (Chen et al 2004), circular (Sze et al 2006), semi circular (Chen et al 2000), annular ring (Chen et al 2005; Ren et al 2006), square ring (Sadat et al 2007a, 2007b), strip loaded (Jang et al 2003) and tapered slot (Verbiest et al 2006b).
Lee et al (2002) proposed a round corner rectangular wide slot antenna. Its dimension is of \( (68 \times 50) \) mm and can achieve 6.17 GHz (2.08 GHz to 8.25 GHz). Chen et al (2003) has introduced a square slot antenna for wideband, which is fed by a widened tuning stub. This antenna can yield a wide impedance bandwidth of only 60\% and has a dimension of \( (72 \times 72) \) mm. Its gain is varying from 3.75 dBi to 4.88 dBi across the operating band. From these studies, it is known that the operating bandwidths of these antennas could not cover the whole FCC defined UWB frequency band from 3.1 GHz to 10.6 GHz.

The microstrip / CPW-fed slot antennas that are with the features suitable for UWB applications are shown in the following survey. In 2004, Chair et al (2004) proposed a CPW-fed rectangular slot antenna with a U-shaped tuning stub. This antenna achieves a wide bandwidth of 110\% with gain varying from 1.9 dBi to 5.1 dBi. But it has the disadvantage of big size i.e. \( (100 \times 100) \) mm. Angelopoulos et al (2006) introduced a microstrip fed circular slot antenna which can operate over the entire UWB band. But, slot diameter is of 65.2 mm. UWB circular /elliptical CPW-fed slot and microstrip-fed antenna designs proposed by Denidni et al (2006) and Sorbello et al (2002) also cover the entire UWB range. These antennas are comprised of elliptical or circular stubs that excite similar-shaped slot apertures. Liang et al (2006b) also proposed UWB circular/elliptical slot antenna, but introduced a U-shaped tuning stub to achieve wide bandwidth. These studies are about the band width coverage of UWB operations. In some applications, it is generally desired to achieve quasi omni-directional radiating patterns and flat gain variations in the operating frequency bands. In those applications, the UWB-MIMO antennas have gained popularity very recently. Several strategies have been identified to enhance the port isolations of the UWB multi-antenna systems; spatial and angular variations (Wang et al 2008; Lin et al 2008; Najam et al 2009), diversity polarization (Mtumbuka et al 2005;
Adamiuk et al 2009), vector antennas (Rajagopalan et al 2007), use of stepped ground plane (Chang et al 2008) and insertion of stubs (Hong et al 2008).

Apart from UWB operation, the antennas are also necessary for the rejection of an interference with the existing wireless networking technologies such as the IEEE 802.11a and the High Performance Radio Local Area Network (HIPERLAN/2), of which the spectrums are allocated within 5.15 GHz to 5.825 GHz. This is because UWB transmitters should not cause any electromagnetic interference on nearby communication systems such as wireless LAN (WLAN) applications. Therefore, a UWB antenna having band notched characteristics is more favourable in practical applications. Several antennas with band stop characteristic have been investigated with the utilization of the advantages of composing simpler RF front ends (Su et al 2005 and Qiu et al 2005). Recently, band notch techniques have been developed for UWB communications to improve the performance. Some techniques are used at the receiver stage, including notch filtering. Another approach for interference suppression is used at the antenna. Based on this approach, various frequency-notched UWB antennas have been developed by inserting different slot shapes (Chen et al 2006; Hong et al 2007; Yuan et al 2008; Wang et al 2008). Moreover, many techniques are used including an embedded inverted U-shape (Kerkhoff et al 2004), an embedded two slits on a circular Monopole (Yoon et al 2004), adjusting a V-shaped thin slot length on the bow-tie shape slot antenna (Kim et al 2004a) and an embedded U-shape on a beveling rectangular patch (Kim et al 2004b). Also, switchable notch band concept was introduced by Kim et al (2007). Multiple band notched UWB antenna has been developed by Zhang et al (2008b).

In this thesis, two elemental CPW fed rectangular slot antennas working in the UWB frequency range are designed and analyzed. Apart from this, Four compact CPW fed rectangular slot antennas for 2.4 GHz WLAN
and UWB systems are proposed and investigated. The design concept of the antennas is explored with different tuning structures such as triangular, rocket, stepped and corrugated stub placed in the wide rectangular slot. Each antenna has a simple geometry, construction with minimum parameters and consistent radiation characteristics required for multifunctional communication systems, which is not studied in the literature. The performance characteristics of these antennas are analyzed extensively.

1.5 ORGANIZATION OF THE THESIS

This research work is organized in 5 chapters as follows.

Chapter 2 gives a brief introduction to UWB and WLAN technology. The history and concept of UWB and WLAN technologies are reviewed. Its advantages as well as applications are addressed. It also covers the fundamental theory and characteristics of UWB antenna. In addition, current regulations and standards are discussed.

Chapter 3 covers a study on a simple CPW fed rectangular slot antenna. Triangular shaped tuning stub is used to broaden the bandwidth so that impedance matching is improved over the entire UWB frequency band. This chapter also addresses the design of a CPW fed slot antenna with notch band function, which can be used for multifunctional wireless communication systems such as 2.4 GHz WLAN and UWB systems. The operation principle of the antenna is illustrated based on the investigation of the antenna performance and characteristics. The key parameters that determine the antenna performances are investigated both analytically and experimentally. Evaluation of time domain behaviour of the proposed antenna is also presented.

Chapter 4 consists of a study on CPW fed slot antenna with rocket shaped tuning stub. Design concept of slotted tuning stub is explained for
UWB operation with band notch function. Antenna for 2.4 GHz WLAN and UWB wireless system is also evolved from the UWB antenna. Performance parameters are also investigated both numerically and experimentally.

Chapter 5 covers the design of a CPW fed rectangular slot antenna with stepped stub structure, which performs well for multifunctional communication systems like 2.4 GHz and UWB systems. It also covers the design and construction of a CPW fed slot antenna with corrugated stub structure, which can be used for 2.4 GHz and UWB multifunctional communication systems. Performance characteristics of these antennas are analyzed and discussed.

Chapter 6 concludes the researches that have been undertaken in this work.