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ABSTRACT

A few years after the early investigation on Ultra WideBand (UWB) wireless system, considerable research efforts have been put into the design of UWB antennas and systems for communications. These UWB antennas are essential for providing wireless wideband communications based on the use of very narrow pulses on the order of nanoseconds, covering a very wide bandwidth in the frequency domain, and over very short distances at very low power densities. In this thesis, new models of T-, L- and U-slotted UWB antennas are proposed by studying their current distribution characteristics. The wideband behavior is due to the currents along the slots' edges introducing an additional resonance, which, in conjunction with the resonance of the antennas main patch. Thus, the resonances overlapping have produced an overall broadband frequency response characteristic. These antennas are considerable smaller than others listed in the references, in which their sizes are less than a wavelength, compact, and suitable for many UWB applications. The configuration of slots type for both patches and feeding strip are considered as a novelty and contribution in this thesis. The geometry of the antenna implies the current courses and makes it possible to identify active and neutral zones in the antenna, thus it will be possible to fix which elements will act on each characteristic. This thesis also investigated the ability of slotted UWB antennas to reject the interference from licensed Fixed Wireless Access (FWA), High PERformance Local Area Network (HIPERLAN) and Wireless Local Area Network (WLAN) within the same propagation environment. Inserting a half-wavelength slot structure with additional small patches gap attached have resulted frequency notched band characteristics. The small patches gap instead of switching that will be used to shortened and lengthen the slot length. The measured return loss, radiation patterns, and phase have good agreement with the simulated results. The antenna provides an omnidirectional pattern with the return loss less than -10 dB and linear in phase.

ABSTRAK

Beberapa tahun setelah penyelidikan awal pada sistem wayarles jalur ultra lebar (UWB), usaha penyelidikan telah ditumpukan pada reka bentuk antena UWB dan sistem komunikasi. Antena UWB ini sangat penting dalam penyediaan komunikasi jalur lebar berasaskan penggunaan denyut yang sangat sempit dalam kiraan nanosaat, meliputi jalur yang sangat lebar dalam domain frekuensi, dan mencakupi jarak yang sangat pendek pada ketumpatan tenaga yang sangat rendah. Dalam tesis ini, model baru antena UWB teralur-T, -L dan -U telah dicadangkan dengan mengkaji pencirian taburan arus. Perilaku jalur lebar disebabkan pada arus sepanjang tepian alur memperkenalkan satu resonan tambahan, yang mana ianya berkaitan dengan resonan antena tampal utama, sehingga pertindihan resonan menghasilkan ciri sambutan frekuensi jalur lebar menyeluruh. Antena-antena ini berukuran agak kecil bila dibandingkan dengan antena lain yang tersenarai dalam rujukan, ukurannya lebih kecil dari satu panjang gelombang, padat, dan sangat sesuai digunakan untuk pelbagai aplikasi UWB. Konfigurasi antenna jenis alur pada kedua tampal dan jalur suapan adalah asli dan boleh dianggap sebagai sumbangan dalam tesis ini. Geometri antena mempengaruhi arah arus dan dengan menentukan zon aktif dan neutral pada antenna, maka elemen yang sesuai dapat ditentukan bagi setiap karakteristik. Tesis ini juga mengkaji kemampuan antena UWB teralur untuk menolak gangguan isyarat daripada Capaian Wayarles Tetap (FWA), Rangkaian Kawasan Tempatan Berprestasi Tinggi (HIPERLAN) dan Rangkaian kawasan Tempatan Wayarles (WLAN) yang wujud dalam kawasan yang sama. Kemasukan sebuah struktur alur separuh panjang gelombang dengan penambahan sela tampal yang kecil berjaya menghasilkan ciri frekuensi jalur *notched*. Sela tampal yang kecil ini digunakan bagi mewakili suatu suis yang digunakan untuk memendekkan dan memanjangkan panjang alur. Keputusan pengujian seperti kehilangan kembali, corak sinaran dan fasa didapati menepati keputusan simulasi. Antena ini memberikan corak sinaran omni arah dengan kehilangan kembali kurang dari -10 dB dan mempunyai sambutan fasa yang lelurus.

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LIST OF ABBREVIATIONS

AUT		Antenna Under Test
CEPT		Conference of European Posts and Telecommunications
CATV		Cable Television
DS-UWB		Direct Sequence Ultra Wideband
DAA		Detect and Avoid
DC		Direct Current
ETSI	:	European Telecommunications Standard Institute
ECC	:	Electronic Communications Committee
ETRI		Electronics and Telecommunications Research Institute
FCC		Federal Communication Committee
FWA		Fixed Wireless Access
FDTD		Finite Difference Time Domain
FR4		Flame Resistant 4
GPS		Global Positioning System
HIPERLAN		High Performance Local Area Network
H-cut		Horizontal cut
IEEE		Institute of Electrical and Electronics Engineers
IDA		Infocomm Development Authority
IR		Impulse Radio
MIC		Ministry of Internal Affairs and Communications
MB		Multi Band
MCMC		Malaysian Communications and Multimedia Commissions
OFDM		Orthogonal Frequency Division Multiplexing
PDA		Personal Digital Assistance
PCB		Printed Circuit Board
RCS		Radar Cross Section

RF	Radio Frequency
SMA	SubMiniature version A
SRR	Split Ring Resonator
SB	Single Band
TEM	Transverse Electric Magnetic
TDMA	Time Division Multiple Access
UFZ	UWB Friendly Zone
UWB	Ultra Wideband
VSWR	Voltage Standing Wave Ratio
V-cut	Vertical cut
WPAN	Wireless Personal Area Network
WLAN	Wireless Local Area Network

LIST OF SYMBOLS

BW		Bandwidth
f_H		High frequency
f_L		Low frequency
f_C		Centre frequency
dBm		Mili decibel
MHz		Megahertz
GHz		Gigahertz
P_{RX}		Antenna received power
P_{TX}		Antenna transmitted power
G_{TX}		Transmit antenna gain
G_{RX}		Receive antenna gain
A		Aperture
c		Speed of light
θ		Theta angle
φ		Phi angle
e_r		Reflection efficiency
P_{rad}		Radiated power
P_{in}		Input power
χ_n	-	Eigenvalue
J_n		Characteristic modes
w_s		Slot width
l_s		Slot length
r		Radius
λ		Wavelength
S_{11}		Return loss
R_e		Real part

I_m	-	Imaginary part
ε_r		Relative permittivity
E-plane		Electric plane
H-plane		Magnetic plane

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CHAPTER 1

INTRODUCTION

1.1 Introduction

Ultra Wideband (UWB) is currently receiving special attention and is quite a hot topic in industry and academia. UWB short-range wireless communication is different from a traditional carrier wave system. UWB waveforms are short time duration and have some rather unique properties. The benefits of UWB technology are derived from its unique characteristics that are the reasons why it presents a more eloquent solution to wireless broadband than other technologies. The unique characteristics are listed below [1].

Firstly, an inherent capability for integration in low cost, low power Integrated Circuit (IC) processes. UWB system based on impulse radio features low cost and low complexities which arise from the essentially base-band nature of the signal transmission. UWB does not modulate and demodulate a complex carrier waveform, so it does not require components such as mixers, filters, amplifiers and local oscillators.

Secondly, UWB has an ultra-wide frequency bandwidth; it can achieve huge capacity as high as hundreds of Mbps or even several Gbps with distances from 1 to 10 meters [2]. Thus, the UWB is a promising technology for Wireless Personal Area Network (WPAN). In recent years, more interests have been put into WPAN technology worldwide. The future WPAN aims to provide reliable wireless connections between computers, portable devices and consumer electronics within a short range. Furthermore, fast data storage and exchange between these devices will also be accomplished. This requires a data rate which is much higher than what can be achieved by existing wireless technologies.

Thirdly, UWB system is extremely fine time and range solution even through lossy, opaque media. And fourthly, UWB system has immunity from multipaths.

Fifthly, non-interfering operation with existing services. In spreading signals over very wide bandwidths, the UWB concept is especially attractive since it facilitates optimal sharing of a given bandwidth between different systems and applications. UWB systems are highly frequency adaptive, enabling them to be positioned anywhere within the RF spectrum. This feature avoids interference to existing services, while fully utilizing the available spectrum. UWB systems operate at extremely low power transmission levels. Therefore, UWB short-range radio technology complements other longer-range radio technologies such as Wireless Fidelity (WiFi), Worldwide Interoperability for Microwave Access (WiMAX), and cellular wide area communications.

Lastly, UWB has low probability of detection and interception. UWB provides high secure and high reliable communication solutions. Due to the low energy density, the UWB signal is noise-like, which makes unintended detection quite difficult. Furthermore, the “noise-like" signal has a particular shape; in contrast, real noise has no shape. For this reason, it is almost impossible for real noise to obliterate the pulse because interference would have to spread uniformly across the entire spectrum to obscure the pulse. Interference in only part of the spectrum reduces the amount of received signal, but the pulse still can be recovered to restore the signal. Hence UWB is perhaps the most secure means of wireless transmission ever previously available [3].

As with any technology, there are always applications that may be better served by other approaches. For example, for extremely high data rate (10’s of Gigabits/second and higher), point-to-point or point-to-multipoint applications, it is difficult today for UWB systems to compete with high capacity optical fiber or optical wireless communications systems. The high cost associated with optical fiber installation and the inability of an optical wireless signal to penetrate a wall dramatically limits the applicability of optically-based systems for in-home or in-building applications. In addition, optical wireless systems have extremely precise pointing requirements, obviating their use in mobile environments.

1.2 Research Background

The UWB technology has experienced many significant developments in recent years. However, there are still challengers in making this technology live up to its full potential. One particular challenge is the UWB antenna design. UWB technology has had a substantial effect on antenna design. The UWB antennas have to be able to transmit pulses as accurately and efficiently as possible. The spectrum allocated certainly requires transmitters and receivers with wideband antennas.

Through literature survey, there are two vital design considerations in UWB radio systems. One is radiated power density spectrum shaping must comply with certain emission limit mask for coexistence with other electronic systems [4]. Another is that the design source pulses and transmitting/receiving antennas should be optimal for performance of overall systems [5]. Emission limits will be crucial considerations for the design of source pulses and antennas in UWB systems.

The main challenge in UWB antenna design is achieving the extremely wide impedance bandwidth while still maintaining high radiation efficiency. By definition, an UWB antenna must be operable over the entire 3.1 GHz - 10.6 GHz frequency range [4]. Therefore, the UWB antenna must achieve almost a decade of impedance bandwidth, spanning 7.5 GHz. The high radiation efficiency is also required especially for UWB applications to ensure the transmit power spectral density requirement achieved. Conductor and dielectric losses should be minimized in order to maximize radiation efficiency. High radiation efficiency is imperative for an UWB antenna because the transmit power spectral density is excessively low. Therefore, any excessive losses incurred by the antenna could potentially compromise the functionality of the system.

Next, the performance of UWB antenna is required to have a constant group delay. Group delay is given by the derivative of the unwrapped phase of an antenna. If the phase is linear throughout the frequency range, the group delay will be constant for that frequency range. This is an important characteristic because it helps to indicate how well a UWB pulse will be transmitted and to what degree it may be distorted or dispersed. The antennas required to have a non-dispersive characteristic in time and frequency, providing a narrow, pulse duration to enhance a high data throughput. It is also a parameter that is not typically considered for narrowband antenna design because linear phase is naturally achieved for narrowband resonance.

In addition, a nearly omni-directional radiation pattern is desirable in that it enables freedom in the receiver and transmitter location. This implies maximizing the half power beam-width and minimizing directivity. It is also highly desirable that the antenna feature low profile and compatibility for integration with Printed Circuit Board (PCB) [6].

A good design of UWB antenna should be optimal for the performance of overall system. For example, the antenna should be designed such that the overall device (antenna and Radio Frequency (RF) front end) complies with the mandatory power emission mask given by the Federal Communication Committee (FCC) or other regulatory bodies [6]. But not the least important, a UWB antenna is required to achieve good time domain characteristics. Minimum pulse distortion in the received waveform, is a primary concern of a suitable UWB antenna because the signal is the carrier of useful information. For the narrow band case, it is approximated that an antenna has same performance over the entire bandwidth and the basic parameters, such as gain and return loss, have little variation across the operational band.

Today the state of the art of UWB antennas focuses in the microstrip, slot and planar monopole antennas with different matching techniques to improve the bandwidth ratio without loss of its radiation pattern properties [7]. The expected antennas are small size, omni directional patterns, and simple structure that produce low distortion but can provide large bandwidth [8].

In the past, one serious limitation of microstrip antennas was the narrow bandwidth characteristic, being 15% to 50% that of commonly used antenna elements such as dipoles, and slots [9]. This limitation was successfully removed achieving a matching impedance bandwidth of up 90%. To increase the matching impedance bandwidth ratio it was necessary to increase the size, height, volume or feeding and matching techniques [10]. Variety of matching techniques have been proposed in the literature reviews, such as the use of slot [11][12], bevel or taper at the bottom of patch [13], notch and partial ground plane [12]. There is a growing demand for small and low cost UWB antennas that can provide satisfactory performances in both frequency domain and time domain.

The planar monopole antennas are promising antennas for UWB applications due to their simple structure, low profile, easy to fabricate and UWB characteristics with nearly omni-directional radiation patterns [6][14][15]. Planar monopole antennas feature broad impedance bandwidth but somewhat suffer high cross-polarization radiation levels. The large lateral size or asymmetric geometry of the planar radiator causes the cross-polarized radiation. Fortunately, the purity of the polarization issue is not critical, particularly for the antennas used for portable devices [16]. There are several UWB planar antenna designs, including planar half-disk antenna [17], planar horn antenna [18], and metal plate antenna [19], have been reported.

Even though UWB is recommended by the FCC of United States (U.S) to operate with maximum in-band effective incident radiated power of -41.3 dBm/MHz within the band from 3.1 GHz to 10.6 GHz, there were tremendous complaints logged against UWB deployment so far [20]. Evaluation of interference between Multiband Orthogonal Frequency Division Multiplexing (MB-OFDM) UWB and Wireless Local Area Network (WLAN) systems using a Gigahertz Transverse Electromagnetic (GTEM) cell has been proposed in [21]. As a result, when the frequencies of the MB-OFDM UWB corresponded to out-of-band radiation for 11a (Band #3), MB-OFDM UWM did not interfere with the WLAN system. In the other hand, when frequencies of the MB-OFDM UWB corresponded to in-band radiation for 11a (Band #4), although the interference power of MB-OFDM UWB was less than receiver noise, the MB-OFDM UWB systems interfered with the WLAN.

Evaluation of interference between Direct Sequence spread spectrum UWB (DS-UWB) and WLAN systems using a GTEM cell has already been presented a year before in [22]. Even if the UWB signal is smaller than the receiver noise of WLAN, the throughput characteristics deteriorate than those in case of the non-interference [22]. Therefore, recently the consideration of UWB antennas is not only focused on an extremely wide frequency bandwidth, but on the ability of rejecting the interference from WLAN 11.a (5725 - 5825 MHz) and High Performance Local Area Network (HIPERLAN) (5150 - 5350 MHz) within the same propagation environment [23].

To avoid the interference between the UWB, WLAN and HIPERLAN systems, a band-notch filter in UWB systems is necessary. However, the use of a filter will increase the complexity of the UWB systems [24]. One of the solutions proposed, as far as antennas are concerned, was to design frequency notched antenna. Therefore, several techniques used to introduce a notched band for rejecting the WLAN and HIPERLAN interference have been investigated, which include such as inserting a half-wavelength slot structure [23][25]-[29], slitting on the edges [30]-[31], utilizing fractal feeding structure [32], and parasitic quarter-wave patch [33] or parasitic open-circuit stub [34]. With the notched band characteristic, the antenna allows to reconfigurable its frequency that only responsive to other frequencies beyond the rejection bands within UWB bandwidth.

1.3 Problem Statements

One of the critical issues in this UWB antenna design is the size of the antenna for portable devices, because the size affects the gain and bandwidth greatly [35]. Therefore, to miniaturize the antennas capable of providing ultra wide bandwidth for impedance matching and acceptable gain will be a challenging task [5]. Planar monopole is used to reduce the size of the proposed antennas. Some novelty UWB planar monopole antennas are investigated in detail in order to understand their operations; find out the mechanism that leads to UWB characteristics and to obtain some quantitative guidelines for designing of this type of antennas.

In order to obtain the ultra wide bandwidth and omni directional radiation pattern, four matching techniques are applied to the proposed UWB antennas, such as the use of slots, the use of bevels and notches at the bottom of patch, the truncation ground plane, and the slotted ground plane. All these techniques are applied to the small UWB antenna without degrading the required UWB antenna's performance. The size of slots, bevels and notches are critically affect to the impedance bandwidth. The distance between truncation ground plane to the bottom of the patch is as matching point, where it determines the resonance frequency. To ensure the broad bandwidth can be obtained, the proper designs on those parameters are required.

The theory characteristic modes are used to design and optimize the proposed UWB antennas as well as some new designs are studied. From the study of the behavior of characteristic modes, important information about the resonant frequency and the bandwidth of an antenna can be obtained. The current behaviors of the antenna are investigated in order to obtain several new slotted UWB antennas. High radiation efficiency and linear phase are also required.

A licensed Fixed Wireless Access (FWA) for point to multipoint radio systems assigned by Malaysian Communications and Multimedia Commissions (MCMC) for 3.4 to 3.7 GHz is considered giving a potential interference to UWB application. This is due to the allocation frequency for this FWA within the UWB range. Thus, the proposed notched antenna is not only designed to reject interference from WLAN, HIPERLAN but also from FWA. In order to meet the goal, the previous designed UWB slotted antenna is chosen as a basic type of reconfigurable slotted UWB antennas. This is due to the slot antennas are good candidate to meet the needs for UWB communication and antenna size reduction due to their compact and broadband. To design this reconfigurable UWB slotted antenna with three notched bands characteristics by using a simple structure of antenna is very challenging task. In this thesis, this antenna is known as reconfigurable UWB slotted antenna. The reconfigurability characteristic means the ability of UWB slotted antenna to reject certain frequencies by using some small gaps, instead of switches, without any degrading the radiation pattern. The controllable slot length by the gaps is intended to reject the required frequencies.

Finally, two types of UWB antennas have been designed and resulted in this thesis. The first is slotted antenna type for general UWB applications. The second is reconfigurable UWB slotted antenna. This second type of antenna is used to reject the interference from existing wireless communication systems within the UWB range such as FWA, HIPERLAN, and WLAN bands. However this is still the newest issue, the existing publications mostly on UWB antenna with notched bands on HIPERLAN/WLAN bands. This thesis is working with an additional notched on FWA band in order to give contribution in UWB antenna development.

1.4 Research Objective

The main objective of this research is to propose small novel types of antennas for UWB applications. The proposed antennas operate over UWB bandwidth (3.1 - 10.6 GHz) and have capability to reconfigurable their frequency to a narrower bandwidth while rejecting from interference from existing FWA, HIPERLAN, and WLAN bands with band notched characteristics.

1.5 Research Scope and Methodology

The research scope is focused on slotted UWB antennas designs which provide an ultra wide bandwidth. Truncation ground plane and notches/bevels techniques are added to improve the impedance matching. The reconfigurability antennas characteristics are achieved by varying the length of slots with on/off the small gaps, instead of switches. In order to achieve the objective, a number of activities have been identified, as outline below:

i. Investigate characteristics of UWB antenna by means of simulation and numerical analysis.
ii. Simulate the UWB antenna design model using antenna simulation software before the actual prototype built.
iii. Integrate some small gaps into the proposed antenna to evaluate the reconfigurable characteristics performance.
iv. Develop a new design prototype of reconfigurable UWB antenna.
v. Antenna performance evaluation and optimization.

1.6 Thesis Outline

The thesis is divided into six chapters. Following is an introductory chapter that defines the importance of this research, objective, and scope. The introduction of UWB technology, the challenges in UWB antenna design, the UWB notched band characteristics and the current issues are also highlighted. The review of UWB applications technology is given in Chapter 2. This chapter begins by the UWB history and definition of UWB signal with some international standardization on it. A wide variety of wideband antennas are presented as well. Some applications applied for this UWB technology such as communication system, radar system and positioning system are discussed. With UWB techniques, it becomes feasible to fuse these unique capabilities into a single system. The review of UWB antenna with notched band characteristics with capability to reject interference generated between other communication systems is presented. Finally, overview of short pulse generation is discussed.

The literature review examined a comprehensive background of other related research works and the fundamental antenna parameters that should be considered in designing UWB antenna, and potential technologies for physical construction given in Chapter 3. Design methodology applied in this proposed UWB antenna and reconfigurable UWB antenna is discussed in detail. The key differences and considerations for UWB antenna design are also discussed in depth as several antennas are presented with these considerations in mind. Several bandwidth enhancement techniques such as various geometry perturbation and Genetic Algorithm will be highlighted in order to obtain optimization in size and performance.

Chapter 4 elaborates on the design methodology mentioned in the previous sections. Some new novelty slotted UWB antennas and reconfigurable UWB antennas are presented and design requirements, general strategy for the design are discussed in detail. By properly design the slots and gaps have provided band notched characteristics at 3.4 to 3.7 GHz and 5.150 to 5.850 GHz. The novelty is in term of the type of slots used and it is considered as a contribution in this thesis.

Chapter 5 presents the results and discussion. Simulated and measured results are compared. The experimental verification process is explained with numerical analysis given. The key contributions in this thesis are highlighted. Finally, some recommendations on further work as well as a concluding statement are given in Chapter 6.