DEVELOPMENT AND ANALYSIS OF WEARABLE TEXTILE ANTENNA (WTA) DESIGN FOR ISM AND HIPERLAN APPLICATIONS

by

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LIST OF SYMBOLS

ε	Electric permittivity (farads/meter)
μ_o	Permeability of air
η_{total}	Total efficiency
σ	Electric conductivity (Siemens/meter)
δ	Loss tangent of dielectric material
ε_r	Relative Permittivity
ε_{eff}	Effective Relative Permittivity
χ	wavelength
ρ	Density of body tissues [kg/m3]
Γ	Reflection coefficient
BW	Bandwidth
C	Maximum transmit data rate,
c	Velocity of light waves in free space
D	The electric flux density
D	Directivity
E	The electric field intensity
f	Frequency
fU	Upper frequency
fL	Lower frequency
fC	Center frequency
G	Gain

Gt	Antenna receiver gain
Gs	Antenna transmitter gain
h	The height of the radiating plate
H	The magnetic field intensity,
J	The electric current density
L	The geometric shape of the radiating element (length)
L_p	Patch length
L_g,	Length of the ground plane
Pt	Received power on antenna receiver
Ps	Received power on antenna transmitter
P_{rad}	Total radiated power
Rin	The location and structure of the feeding stem
$R_{radiated}$	Radiation resistance
R_L	Loss resistance
U	Radiation intensity
W	The geometric shape of the radiating element (width)
Wp	Width of the radiating patch
W_g	Width of the ground plane
W_{stored}	Stored Energy
Z_0	Characteristic impedance
Z_L	Arbitrary load

LIST OF ABBREVIATIONS

BAN	Body Area Network
EBG	Electromagnetic band gap
EM	Electromagnetic
HiperLAN	High Performance Radio Local Area network
ISM	Industrial, Science, Medical
PAN	Personal Area Network
Q	Quality factor
SAR	Specific Absorption Rate
SPA	Suspended Plate Antenna
WBAN	Wireless Body Area Network
WLAN	Wireless Local Area Network
WPAN	Wireless Personal Area Network
WTA	Wearable Textile Antenna

Pembangunan dan Analisis Reka bentuk "Wearable Textile Antenna (WTA)" untuk Aplikasi ISM dan HiperLAN

ABSTRAK

Sejak kebelakangan ini, kepentingan penggunaan antena tekstil yang boleh diguna pakai untuk aplikasi "Body Area Network (BAN)" telah mula berkembang. Dengan kewujudan tekstil yang bersifat konduktif ini membolehkan pembinaan struktur antena boleh dipakai menjadi ringan dan fleksibel yang diperbuat sepenuhnya daripada tekstil. Antena yang dicadangkan ini direka dan dioptimumkan untuk aplikasi ISM (Industri, Sains dan Perubatan) dan HiperLAN (High Performance Radio LAN), dimana, masing-masing mempunyai julat frekuensi 2400 hingga 2480 MHz dan 5150 hingga 5750 MHz. Sebelum ini, reka bentuk antenna mikrostrip yang biasa diguna pakai menggunakan "printed circuit board (PCB) laminates" adalah tidak dapat memenuhi prasyarat "Body Area Network (BAN)" iaitu fleksibel dan boleh berubah bentuk. Sebaliknya, antena yang dicadangkan dalam penyelidikan ini telah direka menggunakan tekstil konduktif, yang dibina menggunakan gabungan gentian polimer / logam yang konduktif dan gentian normal. Prosedur reka bentuk "Wearable Textile Antenna (WTA)" bermula dengan takrif spesifikasi, pemilihan bahan, simulasi menggunakan perisian CST Microwave Studio dan akhirnya, reka bentuk prototaip dan pengukuran. Oleh kerana proses fabrikasi yang digunakan adalah manual, antenna ini telah direka bentuk semudah yang mungkin. Bentuk asas segi empat tepat yang dicadangkan ini kemudian ditambah baikan lagi dengan menggunakan lubang alur dan belahan untuk membolehkan penghasilan getaran dua jalur dan melebarkan jalur lebar. Konsep reka bentuk struktur utama adalah berasaskan antena plat - 60 × 45 mm segi empat tepat digantung di atas 80 × 60 mm lapisan bumi menggunakan 5 mm busa substrat. Antena ini juga telah menjalani beberapa ujian penyelidikan untuk menentukan prestasi keseluruhan.

Development and Analysis of Wearable Textile Antenna (WTA) Design for ISM and HiperLAN Applications

ABSTRACT

In recent years, there has been growing interest in utilizing wearable textile antennas for Body Area Network (BAN) antenna applications. Availability of conductive textiles allowed manufacturing of light-weight and flexible wearable antennas made entirely out of textiles. The proposed antenna is designed and optimized for both ISM (Industrial, Science and Medical) and HiperLAN (High Performance Radio LAN) applications, where operating frequency ranges from 2400 to 2480 MHz and 5150 to 5750 MHz, respectively. Previously, conventional microstrip antenna designs fabricated using rigid printed circuit board (PCB) laminates are unable to conform to BAN's flexibility and deformity prerequisites. On the contrary, the proposed antenna in this investigation is fabricated using conductive textiles, which are built using a combination of conductive polymer/metal fibers and normal fibers. The development procedure of this Wearable Textile Antenna (WTA) starts with its specification definition, materials selection, simulation using CST Microwave Studio software and finally, design prototyping and measurements. Due to the manual fabrication procedure employed, the antenna designed is to be as simple as possible. The proposed basic rectangular radiator is then improved using slots and slits to enable dual-band resonance and broad bandwidths. Its main structural design concept is based on a suspended plate antenna - a 60 × 45 mm rectangular radiating element is suspended over a 80 × 60 mm ground plane using a 5 mm foam substrate. The antenna has undergone several investigations to ascertain its overall performance. Performance of the antenna investigated in free space, placements on different body locations and under different bending radii. S_{11}, gain and efficiency of the antenna in free space and in proximity of human body showed good agreements, indicating design robustness under various operating conditions.

CHAPTER 1

INTRODUCTION

1.1 Overview

In recent years, body centric wireless communication has experienced rapid growth, in line with the vision of wearable computing, which describes future electronic systems as an integral part of everyday clothing. Wearable computing can be seen as a part of the wireless body area network (WBAN). Body area network (BAN) is natural progression from the personal area network (PAN) concept, consisting of a number of nodes and units. Each node is placed on, or in close proximity of the body for the purpose of inter- and intra-body information transmission and relay. These inter- and intra-body nodes can be classified as on-body, off-body and in-body communication (Hall, 2006). On-body communications describe the link between body mounted devices communicating wirelessly. Off-body communication define the radio link between body worn devices and base units or mobile devices located in the surrounding environment. In-body communication is concerned with relaying and exchanging information between wireless implants and on body nodes.

Body centric wireless networks operate in the unlicensed portions of the spectrum. Industrial, science and medical (ISM) band, ranging from 2.40 – 2.48 GHz is unlicensed band under the WBAN and WPAN standards. Typically, a WPAN permits communication within a very short range (around 10 m) which could enable the application of wearable computing devices. Such technologies are Bluetooth, which used as the basis for a new standard, IEEE 802.15 and Ultra wideband (UWB). Figure 1.1 shows the organization of IEEE 802.15 Wireless PAN group (Alfvin, 2003).

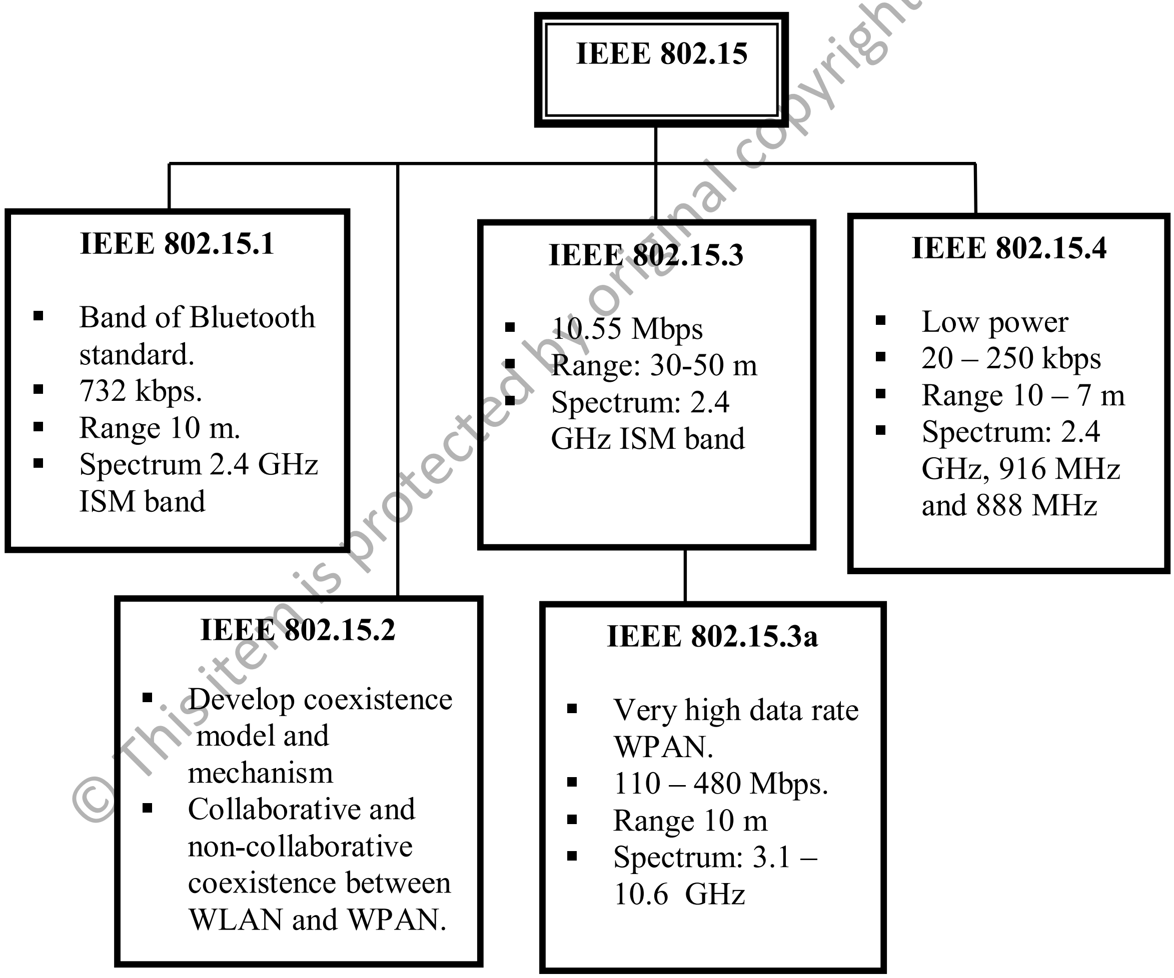

Figure 1.1: Organization of IEEE 802.15 Wireless PAN Group.

Body centric wireless communication has been implemented for indoor wireless communication, which covers a wide variety of situation ranging from communication with individuals walking in residential or schools and hospitals. Body centric wireless networks require body worn antenna or also called wearable antenna. The wearable antenna has to be immune to the presence of human body. This is due to the electromagnetic absorption in tissue, which could result in changes to the antenna's impedance bandwidth, gain and efficiency. In addition, the wearable antenna must have a safe specific absorption rate (SAR) level to avoid excessive electromagnetic radiation to the users. This can be achieved if the antenna has a good shielding mechanism. For users' comfort, the wearable antenna is desired to be light weight, flexible and able to conform to the curvature of human body. In order to fulfil these requirements, the proposed antenna is made purely from textile to guarantee flexibility and comfort.

The proposed design utilize conductive textiles, which are constructed by interpolating conductive metal/polymer threads with normal fabric threads or conductive threads. This results in an ordinary-feel textile/cloth. In the late 1980's conductive textiles were first used as electromagnetic shielding material (Joyner, 1989). Antenna developers have recently found out that conductive textiles are also suitable for antenna design, proving them comparable to conventional antennas designed using printed circuit board (PCB) materials.

While most of the reported wearable antenna has single band frequency for wireless communications around 2.45GHz (Salonen, 2001; Tronquo, 2006; Hertleer, 2007), few are able to operate for dual frequency bands, allowing simultaneous mobile network connections at both 2.45GHz and 5 GHz. The wearable antenna proposed in this research is designed for 5.15 – 5.75 GHz HiperLAN and unlicensed 2.45 GHz ISM (Industrial, Science and Medical) band due to the significant interest in the use of Bluetooth/WLAN modules for body worn devices.

1.2 Problem Statement

Body worn antenna or wearable antenna is an antenna that can be worn or integrated into clothing. This requires its material to be flexible and light weight to gurantee user comfort, besides being able to conform to the curvature of human body (such as around the human arm). There exist limitations for antenna design manufactured from rigid printed circuit board (PCB) materials, such as conventional Rogers, Taconic and FR-4 board. These materials are non-flexible, making it unsuitable for body worn applications. Conductive textiles is seen as the most suitable to fit this purpose: it has good conductivity, enabling it to radiate electromagnetic waves, is light weight and flexible. There are severel existing textile antenan that can operate in dual frequency. The proposed antenna capable for dual band frequency, therefore it can be used for two applications and reduce the numbers of refquired antennas to be used in a single device.

1.3 Research Objective

The objectives of this research are as follows:

i. To investigate suitability and reliability of conductive textiles for antenna design.

ii. To investigate the effects of slits and slots to realize the dual band ability of wearable textile antenna.

iii. To develop wearable textile antenna with safe specific absorption rate (SAR) value which is less than 2 W/kg.

iv. To develop antenna with wide bandwidth with simple design techniques.

v. To develop wearable textile antenna capable to operate for frequencies bands of 2.40–2.48 GHz and 5.15 – 5.75 GHz (ISM and HiperLAN) using a single structure.

1.4 Research Scope

The main scope of the research work presented in the thesis is to design and develop antennas using conductive textiles suitable for body area network. The main purpose is to achieve an efficient, light weight and low profile textile antenna capable of operating in frequencies bands of 2.40 – 2.48 GHz and 5.15 – 5.75 GHz for ISM and HiperLAN using a single structure. The development and analysis of the antennas are performed using CST Microwave Studio simulation software. Fundamental parameters of the antenna namely reflection coefficient (S_{11}), radiation pattern, efficiency and SAR are evaluated using the software. The final stage is the antenna prototype fabrication, measurements and comparison against the simulated result.

1.5 Thesis Outline

Following this introduction section, the thesis comprises of five chapters and the overviews of all the chapters are as follows. Chapter 1 presents the objectives, problem statement, research scope and the overall thesis organization. Chapter 2 discusses the literature reviews and recent state-of-the-art wearable antenna designs. Wearable antenna design considerations such as antenna theories and fundamentals, textile materials, fabrication techniques and analyses required for textile antennas are also included. Chapter 3 describes on the antenna design methodologies, simulation and fabrication steps. Measurement setup for the antenna measurement presented as well.

Chapter 4 discusses results and analysis of the antenna design obtained from simulated and measured results: S_{11}, radiation pattern, gain, efficiency and SAR, both in free space and under bending conditions. Finally, Chapter 5 presents the conclusion of the project and recommendations for future work.