UNIVERSITI PUTRA MALAYSIA

SLOTTED UHF RFID FULL EMBROIDERY E-TEXTILE WEARABLE TAG ANTENNA FOR WBAN APPLICATION

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By

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RFID stands for Radio Frequency Identification. The major purpose that RFID system is built for is to transfer data on a transponder (tag) that can be regained with a transceiver by means of a wireless connection. The contactless Identification (ID) system depends on data transmission by radio frequency electromagnetic (EM) signals, and accordingly, the whole functionality is weather independent and non-line-of-sight. These features for ID system copes the optical barcodes limitations, which are weather dependent, line-of-sight, and manual operation requirement. Most of RFID tags consisted of integrated circuit (IC) or a Chip and an antenna. The IC executes all of the data processing and is energized by extracting the power from the interrogation signal transferred by the RFID reader. The tag antenna controls the amount of power transmitted from the reader to the tag and the reflect signal from the tag to the reader. Nevertheless, there are no restrictions on the physical parameters of the readers antenna, such as being small or planar in size, these restrictions do stratify on the tags antenna. In a matter of fact, the tag miniaturizing in size is limited by the tag antenna size.

Wearable antenna is described as an antenna designed to be an integral part of garment to be worn on the body. The use of radios and antennas in clothing are less cumbersome to the handler compared with traditional handheld whip and radios antennas due to its advantages in long-term use. Wearable antennas were first adopted for home-nursing, hospital patient clothing and clothes rescue workers.

This thesis reports on the design, fabrication, and measurement of Ultra High Frequency (UHF) RFID tag antennas (860 to 960 MHz), which can be used in body-centric applications. The introduced tag antennas are designed and fabricated to

accomplish low tagging costs, good performance, as well as tagging Wireless Body Area network (WBAN) objects with small size tags.

First, full embroidery electro textile RFID tag antenna was designed and tested. In this design, a slotted small size antenna is proposed and designed for wearable body-centric objects UHF RFID (860-960) MHz. The antenna structure embroidered on %100 Polyester as a substrate. Furthermore, E-shaped inductive feeder consists of two opposing symmetrical E-shaped structures to feed the top radiator for antenna. The antenna size is 74×20×2.75 mm^3 at 915 MHz. The peak gain for the antenna reached to 0 dBi at 915 MHz. The antenna bandwidth is 19 MHz (908-927) MHz (power reflection coefficient lower than -3 dB). The measurement result shows very good impedance matching due to the flexibility given by the E-shaped slotted inductive feeder; moreover, there is a very good agreement with simulations results. The design shows a good gain and good performance. This antenna introduced to fill up the need for tagging for long range and mounted for body-centric objects such as access tagging integrated with clothes and in healthcare system.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Master Sains

RFID SLOT FREQUENCY ULTRA TINGGI BERSULAMAN E- FABRIK KEBOLEHPAKAIAN UNTUK ANTENA TAG DIGUNAKAN PADA APLIKASI JALUR LEBAR

By

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RFID bermaksud Pengenalan Frekuensi Radio. Tujuan utama sistem RFID dibina adalah untuk memindahkan data pada transponder (tag) yang boleh diperoleh kembali dengan transceiver melalui sambungan tanpa wayar. Sistem Pengenalan tanpa perhubungan (ID) bergantung kepada penghantaran data melalui isyarat frekuensi radio elektromagnetik (EM), dan dengan itu, fungsi keseluruhannya tidak bergantung kepada cuaca dan bukan garis penglihatan. Ciri-ciri ini untuk sistem ID mengatasi batasan barcode optik, yang bergantung kepada cuaca, garis penglihatan, dan keperluan operasi manual. Kebanyakan tag RFID terdiri daripada litar bersepadu (IC) atau Chip dan antena. IC melaksanakan semua pemprosesan data dan diberi tenaga dengan mengeluarkan kuasa dari isyarat soalalihan yang dipindahkan oleh pembaca RFID. Antena tag mengawal jumlah kuasa yang dihantar dari pembaca ke tag dan menandakan isyarat dari tag kepada pembaca. Walau bagaimanapun, tidak ada sekatan pada parameter fizikal antena pembaca, seperti saiz kecil atau planar, sekatan ini melakukan stratifikasi pada tag antena. Sebenarnya, saiz miniatur dalam saiz dihadkan oleh saiz tag antena.

Antena boleh pakai digambarkan sebagai antena yang direka untuk menjadi sebahagian daripada pakaian yang perlu dipakai pada badan. Penggunaan radio dan antena dalam pakaian kurang rumit kepada pengendali berbanding dengan cambuk tangan tradisional dan radio antena kerana kelebihannya dalam penggunaan jangka panjang. Antena boleh pakai pertama kali digunakan untuk rumah-kejururawatan, pakaian pesakit hospital dan pekerja penyelamat.

Tesis ini melaporkan reka bentuk, fabrikasi, dan pengukuran tag antenna Ultra High Frequency (UHF) RFID (860 hingga 960 MHz), yang boleh digunakan dalam aplikasi berasaskan badan. Antena tag yang diperkenalkan direka dan dibuat untuk mencapai kos penandaan yang rendah, prestasi yang baik, serta menanda Wayar Tubuh Wayar (WBAN) dengan tag saiz kecil.

Pertama, sulaman penuh elektro tekstil RFID tag antena direka dan diuji. Dalam reka bentuk ini, antena bersaiz kecil dicadangkan dan direka untuk objek UHF RFID (860-960) MHz berasaskan badan yang boleh dipakai. Struktur antena bersulam pada 100% Polyester sebagai substrat. Tambahan pula, penghawa induktif berbentuk E terdiri daripada dua struktur berbentuk E simetri yang menentang untuk memberi makan radiator atas untuk antena. Saiz antena ialah 74×20×2.75 mm^3 pada 915 MHz. Hasil puncak bagi antena mencapai 0 dBi pada 915 MHz. Jalur jalur antena ialah 19 MHz (908-927) MHz (pekali pantulan kuasa lebih rendah daripada -3 dB). Hasil pengukuran menunjukkan padanan impedan yang sangat baik disebabkan oleh fleksibiliti yang diberikan oleh suapan induktif berbentuk E. Selain itu, terdapat keputusan yang sangat baik dengan hasil simulasi. Reka bentuk menunjukkan kenaikan yang baik dan prestasi yang baik. Antena ini diperkenalkan untuk mengisi keperluan penandaan untuk jangka panjang dan dipasang untuk objek yang berpusatkan badan seperti penandaan akses bersepadu dengan pakaian dan sistem penjagaan kesihatan.

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I certify that a Thesis Examination Committee has met on 21 December 2017 to conduct the final examination of Bahaa Abbas Dawood on his thesis entitled "Slotted UHF RFID Full Embroidery E-Textile Wearable Tag Antenna For WBAN Application" in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Master of Science.

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LIST OF ABBREVIATIONS

BAN_s	Body Area Networks
PAN_s	Personal Area Networks
GPS	Global Positioning System
ICD+	Industrial Clothing Design
GNSS	Global Navigation Satellite System
EPDM	Ethylene-Propylene-Diene-Monomer
ASIC	Application Specific Integrated Circuit
BWp	Percentage Bandwidth
BWr	Ratio Bandwidth
CST	Computer Simulation Technology
EAS	Electronic Article Surveillance
EIRP	Equivalent Isotropic Radiated Power
PTFE	polytetrauorethylene
EM	Electromagnetic
EPC	Electronic Product Code
ERP	Effective Radiated Power Gigahertz
GHz	Gigahertz
HDPE	High Density Polyethylene
HF	High Frequency
HFSS	High Frequency Structure Simulator
HIS	High Impedance Surface
HPBW	Half-Power Beamwidths
IC	Integrated Circuit

ID	Identification
IFF	Identification of Friend or Foe
ISM	Industrial Scientific and Medical
LF	Low Frequency
MHz	Megahertz
PBG	Photonic Band Gap
PCB	Printed Circuit Board
PIFA	Planar Inverted F Antenna
PP	Polypropylene
PRC	Power Reflection Coefficient
PTC	Power Transmission Coefficient
RF	Radio Frequency
RFID	Radio Frequency Identification
SAW	Surface Acoustic Wave
SHF	Super High Frequency
SMA	Sub Miniature Version A
SRD	Short Range Devices
UWB	Ultra-Wideband
VNA	Vector Network Analyzer

CHAPTER 1

INTRODUCTION

1.1 Introduction

RFID stands for Radio Frequency Identification which is an automatic wireless identification system that employs low power electrically active tags. This wireless technology uses low-cost communication devices embedded in many chips that operates remotely un-obstructively and transparently to track objects' origin, physical location, and ownership information. This technology enables easy identification of distant tags through electromagnetic propagation at ultra-high frequencies (UHF) for communication. There are two major components of passive RFID tags namely; RFID tag integrate circuit (IC) and tag antenna. A passive tag is usually powered to run its data transmission from external source obtained from incident electromagnetic waves. The tag is relatively simple, maintenance-free, and economical due to its passiveness which enables huge commercial applications such as asset tracking and ticketing. However, future developments using RFID depends on the migration to a more intelligent wearable system from the current traditional embedded systems. The more intelligent systems are augmented with different biochemical and ambient sensors capable of identifying physical factors in its environment that provides continuous monitoring of vital signs.

1.2 Problem Statement and Motivation

Generally, in terms of technology, a body-centric system is highly interdisciplinary and the overall quality of a system depends on the performance of systems' single components. The efficiency of the system depends on their ability to interoperate and communicate reliably and effectively with one another. These requirements poses a great challenge to the wearable antennas, thus, inspiring RF designers to find efficient and economical design approaches and materials for future antennas.

Integrated antenna-clothing without degradation in performance of antenna is one of the major issues facing implementation of wearable antenna. Copper has been used as conductive element in antenna due to its superior conductivity features. But, its structural non-flexibility does not allow is to conform effectively to the clothing surface in wearable applications. Therefore, it has become highly imperative to use light- weight textile materials that conform to RF characteristics. Furthermore, durability is also an important issue to be considered in selection of wearable antenna materials due to environmental special effects such as dirt and humidity and their vulnerability to stretching, mechanical compression and bending deformations.

For the past decade, advances in electro-textiles or electrically active textiles integrated with computational features have been on the increase [1][2]. The use of these technology for electrical purposes is gradually emerging as a new concept. The major concept of this development is to provide enabling techniques for large-scale manufacturing of sensing systems for unique applications such as military hardware, consumer electronics and personal healthcare systems [3]–[6][7]. Conductive sewing threads are used in a computer embroidery machine to develop electro-textiles. A non-conductive fabric surface could be electro-plated with pure metal or an alloy [2] [8][9]. The manufacturing of the conductive threads are carried out by making strands out of the conductive and non- conductive fibres. A single metallic fibre could serve as a conductive thread, but, could be fragile and vulnerable when subjected to external force due to its thin like structure that may inhibits its use in embroidery machine. Therefore, non-conductive fibres are used as a shield for the conductive fibres and improve its toughness without affecting its electrical functionality. Even though, RFID offer tremendous benefits to supply chain management, there exist several issues arising due to the increase in applications using RFID technology [10], [11].

Among the major challenges of RFID E-textile in body centric area are:

1- The flexibility of the full embroidery tag.
2- Degradation of RFID system performance and reliability in presence of the personal area networks (PANs) and body area networks (BANs) objects.
3- Small and in-expansive E-textile embroidery antenna.
4- Matching of Impedance between the antenna and the IC chip.

Practicable solutions are required to enable full and comprehensive deployment of RFID, to achieve the vision of tagging objects down to item level. Therefore, in this thesis, the main target is to solve the first and the second challenges listed above, using full textile materials for the tagged structure. Since one of the major problems of RFID E-textile implementation is the decrease in performance when tagging operating near human body. The tagging of objects at case, pallet, and item levels would involve body-centric objects. Meanwhile, the third challenge above regarding size and cost should be emphasised while tackling the first and second challenges. The third challenge become very important particularly when item level tagging is included. In order to lower the tags cost in comparison to the conventional tags, the tags should be made from inexpensive materials and simple to manufacture. Yet, the ohmic loss will increase with decrease in size of the antenna [12], and thus the efficiency will decrease. Therefore, to maintain balance between the tag performance, size and cost is a challenging task. An E-textile embroidery microstrip structure have been adopted throughout this research for the purpose of good performance within the vicinity of human body and thus good read range with size reduction.

This thesis also itemizes on the fourth challenge listed above which is of an essential importance for proper tag antenna design. Microchip vendors manufacture variety of Application Specific Integrated Circuits (ASIC) that are available in the market with different impedance values.

1.3 Research Questions

The challenges above create the research question. The following research questions have been framed to set the direction for this research:

1- What are the available UHF RFID tag designs used currently?
2- What is the need for developing the wearable tag?
3- What problems arise when use the conventional tag?
4- What is the proposed design that would be able to resolve the problems of existing?
5- Can the proposed design attain higher efficiency than existing approach?

1.4 Objectives of Study

The main objectives of this research is to design and develop a passive UHF RFID tags for wearable wireless body-centric systems requiring light-weight, conformal, and integrable tag antennas. To meet the abovementioned challenges and research questions, this study focused on the following three main objectives:

1- To investigate the wearable UHF RFID tag antenna in body centric area objectives.
2- To design small size RFID tag and full embroidery textile with good read range within the vicinity of human body.
3- To conduct measurement in order to validate the performance of the designed E-textile tag antenna, complex impedance and read range of small tag antenna.

1.5 Scope of Research

The scope of this thesis is to design a new wearable embroidery textile for RFID body centric applications integrated with the clothes. The microstrip textile tag antenna designed to be operating close to the human body. The flow of this study is demonstrated in Figure (1.1). The continuous-lines represent the direction followed in this thesis to achieve the objectives, while the dashed-lines are referring to other related research areas that are outside the scope of this work. The slotted patch operate at UHF band (860-960 Mhz). 100% polyester used as a substrate and E-opposite feeder utilized.

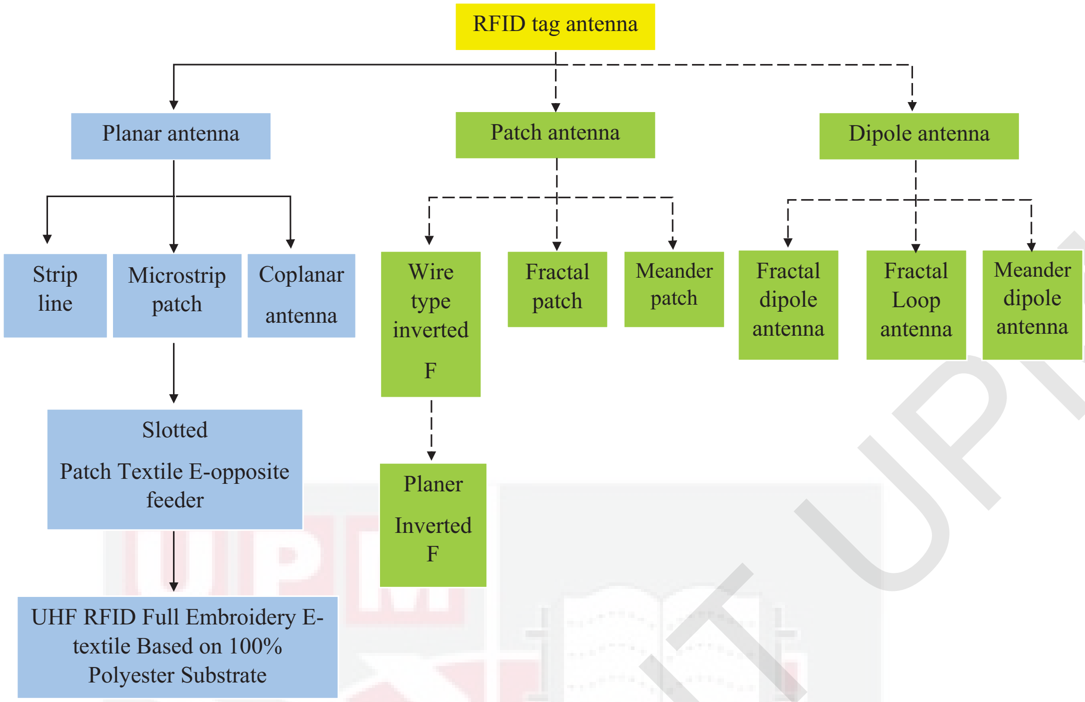

Figure 1.1 : Scope of study

1.6 Research Methodology

Firstly, to achieve the objectives of this research, extensive research on RFID tag antennas and metamaterial-based antenna was performed to understand their fundamentals and how these types of antennas can be used for RFID applications. Determining the inexpensive material was next for the antenna construction with convenient chips after identifying the antenna parameters and getting the chip impedance, which were used in the design. Then, the performance of RFID tag antennas were experimented and analysed using 3D full-wave electromagnetic simulator [13]. In addition, it is highly imperative to understand how these types of embroidery textile tags are attached to human body. Therefore, unique methods of integration textile tagged antennas would be designed for RFID applications and validated. The developed methodology for the design RFID tag antennas is illustrated in the flow chart depicted in Figure (1.2).

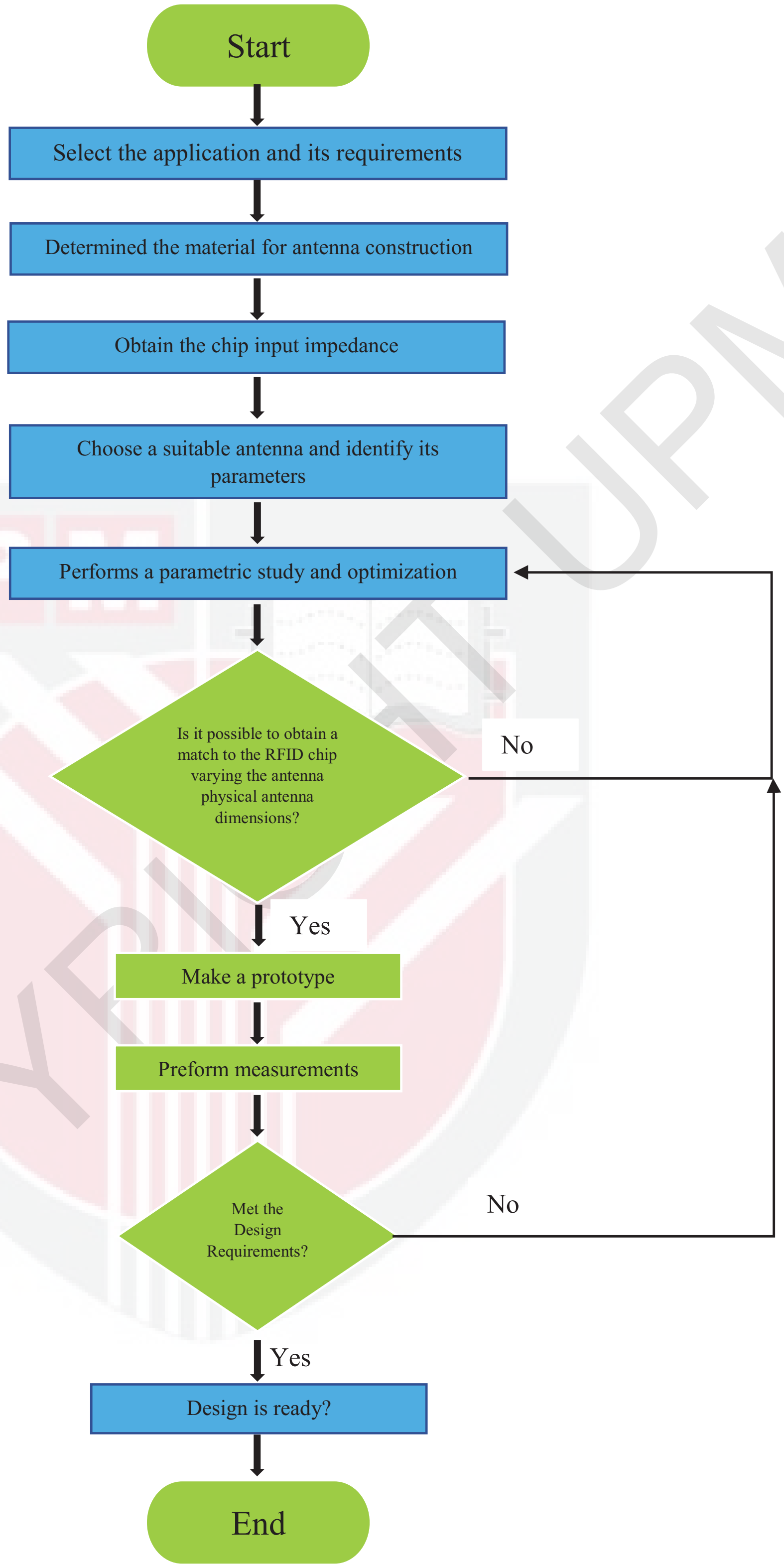

Figure 1.2 : Methodology Design Flow of RFID Tag Antennas

1.7 Layout of Thesis

This thesis is structured into five chapters and are summarized as follows:

Chapter 1 provides general introduction to the research area, and identifies the current problems in designing RFID tag antennas that motivated this research. It also introduces the goal, objectives, methodology, scope of research as well as the organization of thesis writing.

Chapter 2 presents a literature review on RFID system and E-textile wearable tag antennas. It first provides a background of RFID technology and some details about their classes and types. The wearable types also presented. Then some details are provided about RFID tag antenna design considerations as well as some recent designs and applications. Finally, a summary ends the chapter.

Chapter 3 describes the methodology used in determining the tag materials and designs in an attempt to improve the antenna read range. The body effective on the behaviour of antenna radiating and the statistical catalog of human body models that are used in the simulation and the measurement setup are discussed. Also, the slotted microstrip patch antenna structure and the parasitic study are discussed in this chapter.

Chapter 4 contains a description of the new design of small embroidery textile tag antenna with read range enhancement for body centric objects which is based on the structure of slotted transmission line technology. Some antenna parameters and their effects on antenna self-resonant frequency are studied. The performance characteristics in terms of reflection coefficient, gain, resonance frequency and bandwidth are presented. Comprehensive analyses of the simulated and measured results are carried out for validation.

Chapter 5 presents the conclusions and recommendations based on the data obtained and the result of the analysis carried out for further investigation or action. Also, the research contributions and potential future works are suggested.

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