EMBROIDERY LEAF-SHAPED DIPOLE ANTENNA FOR WEARABLE COMMUNICATION SYSTEM

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ABSTRACT

The fast development of technology and the demand of mobile wireless communication have increased due to the advancement of wearable devices. Industries are continuing to search for devices that are compact, robust, portable, unobtrusive, cost-effective and easy to use. The feature of fabric antenna technology is responding well to the current trend towards wearable and flexibility materials due to its flexibility and convenient to users. Therefore, this thesis focuses on designing and analysing the type of embroidery antenna using conductive threads. Embroidery is usually used in the clothing industry to incorporate complex patterns into garments. A leaf-shaped dipole textile antenna at Industrial, Scientific and Medical (ISM) band is chosen to be further investigated. The proposed dipole antenna is designed to operate at 2.45 GHz. The effect of conductive threads with three different types of stitching is analysed. The first type of stitching leaf-shaped dipole antenna is circular followed by vertical and horizontal stitch respectively. These three types of embroidery antenna are investigated in terms of bending, crumpling and wetness. From the return loss measurement, the antenna bandwidth with circular stitch shows better performance with optimum resonances compared to the vertical and horizontal stitching. The bandwidth of circular stitching for bending and crumpling investigation process shows 25% and 40% improved performance respectively. In wetness investigation, the presence of water has modified the properties of the substrate yields change in the operating frequency. The antenna performance after the wetness is not as similar to the earlier state (before wetness experiment) due to the shrinking effect and slight property changes on the fabric material. The measured results confirm that the circular stitch is more suitable for leaf-shaped dipole antenna design. Thus, it can be concluded that different stitches give different results for leaf-shaped dipole antenna. These results are in good agreement to the previous work where stitching types are important aspect to be taken into account to ensure good antenna performances.

ABSTRAK

Perkembangan teknologi yang pesat dan permintaan komunikasi wayarles mudah alih telah meningkat dalam menghasilkan peranti yang termaju dan boleh dipakai. Industri terus mencari peranti yang kompak, teguh, mudah alih, tidak mengganggu, kos efektif dan mudah digunakan. Ciri teknologi antena fabrik bertindak balas dengan baik kepada trend semasa ke arah bahan yang boleh dipakai dan fleksibel. Oleh itu, tesis ini memberi tumpuan kepada merancang dan menganalisis jenis antena sulaman dengan menggunakan benang konduktif. Sulaman biasanya digunakan dalam industri pakaian untuk memasukkan corak kompleks ke dalam pakaian. Bentuk daun dwikutub antena tekstil pada jalur Industri, Saintifik dan Perubatan (ISM) telah dipilih untuk dikaji. Frekuensi operasi antena dwikutub adalah pada 2.45 GHz. Kesan benang konduktif dengan tiga jenis jahitan yang berbeza telah dianalisis. Jenis pertama antena dwikutub berbentuk daun jahitan adalah berbentuk bulatan diikuti oleh jahitan menegak dan mendatar masing-masing. Ketiga-tiga jenis antena sulaman telah disiasat dari segi lenturan, susut dan basah. Dari pengukuran kehilangan balikan, lebar jalur antena dengan jahitan bulat menunjukkan prestasi yang lebih baik dengan resonans optimum berbanding dengan jahitan menegak dan mendatar. Proses penyiasatan bagi lentur dan mencekam mencapai pertambahan sebanyak 25% dan 40% untuk lebar jalur.
Dalam siasatan basah, kehadiran air telah mengubah sifat-sifat substrat dan menyumbang kepada perubahan dalam kekerapan operasi. Prestasi antena selepas kebasahan tidak sama dengan keadaan terdahulu (sebelum percubaan basah) akibat kesan mengecil dan sedikit perubahan pada struktur kain.Hasil yang diukur mengesahkan bahawa jahitan bulat lebih sesuai untuk reka bentuk antena dwikutub berbentuk daun. Oleh itu, dapat disimpulkan bahawa jahitan yang berbeza memberi hasil yang berbeza untuk antena dwikutub–berbentuk daun. Keputusan ini sesuai dengan kerja sebelumnya di mana jenis jahitan adalah aspek penting yang perlu dipertimbangkan untuk memastikan persembahan antena yang baik.

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LIST OF SYMBOLS

ε_r	-	Relative permittivity
ε	-	Absolute permittivity
ε_0	-	Permittivity in free space
$\tan \delta$	-	Loss tangent
σ	-	Conductivity
ø	-	Degree of flare angle

LIST OF ABBREVATIONS

RF	-	Radio Frequency
PIFA	-	Planar Inverted-F Antenna
UHF	-	Ultra-High Frequency
CST	-	Computer Simulation Technology
UWB	-	Ultra-Wide Band
PCA	-	Photoconductive Antenna
FEM	-	Finite Element Method
PEN	-	Polyethylene Naphtalene
EBG	-	Electromagnetic Band Gap
GA	-	Genetic Algorithm
PMC	-	Perfect Magnetic Conductor
WLAN	-	Wireless Local Area Network
ISM	-	Industrial, Scientific and Medical
RFID	-	Radio Frequency Identification
IC	-	Integrated Circuit
FM	-	Frequency Modulation
MCEY	-	Metal Composite Embroider Yarn
PVC	-	Poliyvinyl Chloride
PEC	-	Perfect Electric Conductor
EMF	-	Electromagnetic Field
VNA	-	Vector Network Analyzer
SMA	-	Sub-Miniature Version A
CT	-	Copper Textile

CHAPTER 1

INTRODUCTION

1.1 Research Background

Wearable devices are getting more attention these days due to the demand of mobile wireless communication. Industries are continuing to search for devices that are compact, robust, portable, unobtrusive, cost-effective and easy to use. Integrating antenna into clothing fabric of a wearer is more likely to be adapted by end-users because of its comfort. Its high potential of being adapted may be useful so that it will be available and operational when the situation requires it. For example, in a situation which requires the user to record health performances, it is more comfortable for the user to use wearable antenna.

The features of fabric antenna technology is responding well to the current trend in moving towards reducing the size and use of materials. It will have various applications in numerous markets. For example, in military, it may be possible to integrate the technology into a ‘monitoring suit’ in which when worn, an army can remotely transmit vital reading location of an enemy to a responsible professional, thus enabling an army to make a move. Other target areas include sport/leisure and healthcare services. Therefore, it is significant to develop textile-based antenna systems, together with their associated feed networks. Various advantages of this system include ease of fabrication with the ability to transform a simple fabrication process and conformal systems that provide assurance or security advantages which are not conformal antenna to be damaged or cause damage. Some papers provided a review of various aspects regarding substrate and conducting element characterization of wearable antenna system [1-3]. A detailed investigation of body-centric involving Wireless Body Area Network (WBANs), Wireless Sensor Networks (WSNs) and Wireless Personal Area Network (WPANs) communications between multiple wearable antennas was described in [4]. Some review in wearable antenna regarding manufacturing technique was presented in [5]. The needs of choosing a suitable fabric on wearable antenna investigated by Lija was in [6].

Antenna is a device that transmits and receives electromagnetic signals. The performance of an antenna in a wireless communication system will determine the efficiency of the system. Hence, choosing the right antenna to be used is really important. Particularly for textile antenna, apart from choosing the suitable type of antenna, it is necessary to identify a suitable fabric that supports the flexibility to be implemented on textiles that can be worn as a part of clothing. Moreover, wearable antennas are also cheap, light and can work in a wide range of frequencies. [7], [8]

1.2 Problem Statement

Radio communications experts and antenna manufacturers struggle with the conflicting requirements of size, efficiency, bandwidth, and cost as they design the advanced communications systems of the future. Radio waves, particularly in lower frequencies, are just so long and still in ‘traditional’ design as fabricated on FR-4 substrate [9] . However, its drawback invites new studies to be carried out. Conventionally, antenna is fabricated in rigid structure and it is not suitable for wearable application. As technology keeps evolving and maturing, so does the wearable antenna. Wearable devices can be widely used in large number of applications including location tracking, medical sensor, spacesuit, military, fashion, and et cetera. [10–13]. For example, the usage of RF antenna for defense applications is one of the least glamorous yet most essential subsystems in all of military systems design. Wireless communications capability is crucially needed, yet users are demanding even smaller, lighter, cheaper and more body friendly antennas to support an increasing appetite for data communications, even on the forward edge of the battlefield. The problem is the inability of antenna designers to shrink the size and weight as quickly as integrated circuit for wearable application systems. For the application stated above, it requires small size of antenna to transmit and receive RF energy with acceptable efficiency within 60% of range and needs to be body friendly for users [14].

Wearable antennas are introduced to be more flexible and low cost compared to conventional antennas. Textile antenna demands uniform which has radiating signals in all directions with reasonable gain of communication systems for both base station and receiving devices. Therefore, some types of antennas such as Planar Invented-F antenna (PIFA) [15], patch antenna [16], dipole antenna [17], folded dipole [18] and meander line antenna meet the demands of developing communication equipment as the research of antennas particularly focuses on some aspect. For instance, the issue of reducing the size of antennas while maintaining higher radiation efficiency is a crucial part in designing the best antenna. Clearly, compared to communication equipment, antenna's dimension demands a large size for having a better performance.

Another challenge is about miniaturized size for designing wearable antenna. Besides, the most important aspect in wearable antenna is the reliability of the antenna itself in transmitting and receiving the signal in all directions. For example, the moving user would be able to be tracked and monitored from base station communication at any position of the user in the room. The antenna's performance is up to resisting various environment aspects such as the relative humidity and bending, wetness and crumpling condition. Another challenge in smart clothing is a compromise between the characteristics of functional textiles flexible for electronics and light simultaneously. Conductive textile is one of the solutions. Previous researchers had pointed out that these materials provide both flexibility and electromagnetic characteristics [19–21]. Making antennas using textile materials of different conductivity and methods have been discussed previously [22–24]. Placing electronic devices into daily clothes is one of the best ways to have hands-free and low profile portable personal mobile communication system. However, several wearable antennas are not comfortable for the users when involving the movement and posture of the bodies and it is also not easily attached to the clothes as the substrate and conducting elements are patched by adhesive in order to make them attached. Thus, it tends to dislocate from substrate whenthe movement of human body is involved [25].

For this research project, it highlights embroidered antenna by using conductive threads. Embroidery is usually used in the clothing industry to incorporate complex patterns into garments. The embroidered designs are easily modified, accurate, and the computerised embroidery provides high speed and low cost fabric design in mass production. Special conductive yarn offers both flexible fiber characteristics and conductivity and can be used for embroidering the antenna [26]. Flexible textile antenna RF performance is dependent on several factors including humidity environment [27] and the dimensions of antenna. The most crucial factors in embroidery antenna are the stitch direction and stitch spacing between two parallel threads which play important roles in current distribution. The current distribution on the surface of the embroidered antenna results on the antenna performance. The findings of stitching issues has been studied in a previous research [28]. In general, the stitch direction needs to be parallelled with the preferred current direction. Furthermore, high density stitch spacing results in making the resonant frequency closer to the desired frequency and achieving high antenna gain and efficiency.

1.3 Research Objectives

There are many researches that have been conducted regarding textile antenna and several products are already in the markets. As embroidery is one of the main elements in producing textiles, the main objectives of this project is to design the compact size, comfortable and robustness textile antenna for wearable communication system. The objectives can be written as follows:

1) To design and fabricate the embroidery dipole antenna at ISM band at 2.45 GHz.

2) To study the effect of stitching types on performances of embroidery antennas.

3) To explore the physical behavior like bending, crumpling and wetness for embroidery antenna.

1.4 Scope of Works

The objectives of this research highlighted the important role of embroidery antenna for military application. Several steps have been considered to complete the proposed antenna in order to accomplish the objectives stated. The steps include a comprehensive literature review regarding the study of previous researches on single band design, multiband, low and high UHF textile antenna. Thus, this gives a great significance in strengthening the basic knowledge of textile antenna design and discovering the expected results and limitation aspect in producing a better design of the embroidery antenna. Dipole antenna played up as the main design in order to achieve the desired objectives. Simultaneously, previous study regarding compact dipole antenna has been reviewed. Dipole antenna has an omnidirectional pattern that radiates in all direction. Based on the objectives stated, dipole embroidery antenna is simulated to operate at ISM band at 2.45 GHz. ISM band is an unlicensed band that can be used in any application.

The action begins with designing the antenna by using Computer Simulation Technology (CST) which is electromagnetic software. The antenna design has undergone the simulation and analysis on performance results. The performances would enlighten the return loss, radiation patterns, current distributions, efficiency, gain and others. The density of conductive threads has been determined by measuring the general unit of thread or yarn based on the previous research [26]. Meanwhile, the characterization of textile material for both permittivity and loss tangent has been determined by using coaxial probe technique as stated in previous study [28]. The electromagnetic data criterion is required before the antenna undergoes the simulation process. The performance of the antenna design has been optimized at 2.45 GHz with parameter sweeping technique provided by CST software. The performance result of the antenna in simulation process is compared to the fabricated antenna.

After optimization, the simulated antenna is fabricated using two different conductive materials which are copper textile and conductive threads to evaluate the antenna performance. For conductive threads, it collaborates with embroidery stitching where the thread is sewed manually into felt fabric following the leaf shape dipole antenna. The measurement results in terms of return loss, bandwidth, radiation pattern, current distribution as well as gain and efficiency by using network analyzer in anechoic chamber are presented to validate the usefulness of the manuscript design. Next, the embroidery antenna is investigated under bending, crumpling and wetness in order to discover the antenna's performance like bandwidth and frequency resonant.

1.5 Thesis Outline

This thesis outline consists of seven chapters including introduction, literature review, research methodology, characterization of materials, planar textile antenna, embroidery antenna and conclusion. The main objective in this research is to design and fabricate the embroidery antenna at 2.45 GHz. Then, the embroidery antenna will be stitched with three different types of stitching and the performance of these three types of stitching will be analyzed. For the next part, these three types of stitching will be tested under bending, crumpling and wetness condition. The measurement result will be discussed in details. Overall, chapter 1 is briefly describing research background, problem statement, research objectives and also the scope of work.

Chapter 2 discusses the theory of several types of antenna used in this study. The study that has been done by previous researchers is reviewed in this chapter too. Besides, overview of wearable antenna including textile antenna, embroidery antenna and textile antenna critical design are also discussed in details.

In chapter 3, the methodology of the research project is explained technically. Initially, the flow chart is presented to show the flow of the research that will be completed. Then, its continues with the simulation of the design. The fabrication process that involves embroidery needle, embroidery thread and also embroidery stitches are also discussed in details.

Chapter 4 describes the characterization of the materials. Initially, the dielectric involves permittivity and loss tangent will be explained in details. The measurement of the dielectric and the coaxial probe method are also elaborated in this section. Since this research revolves within textile materials for the embroidery antenna, the methodology involved in the textile material characterization is explored.

Chapter 5 focuses on the design of planar textile antenna as well as embroidery design structure. The chapter starts with a review of dielectric of fabric used in the investigation that has been measured in the previous chapter. Then, a discussion on the proposed antennas is followed. The initial design is planar straight dipole antenna, continuing with the diamond dipole and finally the proposed antenna which is a leaf shaped dipole antenna is designed and fabricated.

Chapter 6 investigates the performance of the leaf-shaped dipole antennas. Initially, the proposed designs are tested with the conductive threads on the leaf-shaped dipole antenna fabricated with conductive textile. Then, the leaf-shaped dipole antennas are stitched with three different types of stitching. For the next part, the leaf-shaped dipole antenna is fabricated with fully conductive threads without conductive textile. The performances of these three different types are explained in details. The proposed antenna design is also tested in a number of wearable experiments, including bending, crumpling and wetness. The measurement results are then discussed for a possibility of a practical realization in the wearable communication system.

Finally, chapter 7 concludes the overall research study with the research findings as well as by highlighting the key contributions. Recommendation and also future research works are also suggested for the better achievement in the future ahead.

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