MULTIBAND TEXTILE ANTENNA FOR WEARABLE APPLICATION

MOHD EZWAN BIN JALIL

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Specially dedicated to my beloved father and mother, Jalil Bin Rusek and Roshani Bte Awang, my sibling and my family, for their encouragement, love and support.

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ABSTRACT

In recent years, wearable computing system, also called “smart clothing”, has been developed for monitoring, tracking and navigating application especially in medical, healthcare and military sectors. One of the considerations for wearable system is to design suitable antenna with good performance while providing comfort to the user. Robustness, flexibility and compactness are required as wearable antenna. In this project, textile antennas using denim materials which has $\varepsilon_r = 1.70$ and $tan\ \delta$ = 0.085 are chosen to fulfil the requirements of the antenna. The antenna model is designed using Microwave Studio CST software. Several antenna prototypes are fabricated and evaluated with different conducting elements (*Shieldit* fabric and copper foil tape). For the multiband antenna, a triple band fractal Koch dipole antenna was designed to operate at 0.9 GHz, 2.45 GHz and 5.8 GHz. The fractal Koch antenna is reduced to about 15% of length size of the straight dipole antenna. Both antenna performances with different conducting elements were observed in terms of return loss, bandwidth, radiation pattern and gain. Three types of analysis are evaluated on fractal Koch multiband antenna which measures performance with bending, human body and wet conditions. The performances of the antennas are conducted based on resonant frequency and bandwidth. From the analysis, it is found that the bending of copper fractal antenna on human body drastically shifted the resonant frequency from 0.90, 2.45 and 5.16 GHz to 0.49, 1.16 and 3.03 GHz. The suitable antenna placement on human body has been discovered at the chest with resonant frequencies of 0.80, 2.56 and 5.16 GHz and the backside with resonant frequencies of 0.88, 2.48 and 5.8 GHz. The fractal Koch multiband antenna maintains performance with less 3% of water absorption in the antenna under wet conditions. The performance of copper tape was shown to be more profound than *Shieldit* antenna in terms of return loss, radiation pattern and gain due to the minimization of the electrical loss of material. However, *Shieldit* antenna is more flexible and robust than the copper antenna.

ABSTRAK

Pada tahun kebelakangan ini, sistem komputer boleh dipakai yang juga dikenali sebagai "pakaian pintar" telah dibangunkan untuk memantau, mengesan dan mengemudi aplikasi terutama dalam bidang perubatan, penjagaan kesihatan dan ketenteraan. Salah satu pertimbangan untuk sistem boleh dipakai ialah untuk mereka bentuk antena yang sesuai dengan prestasi yang baik disamping memberi keselesaan kepada pengguna. Keteguhan, fleksibiliti dan saiz adalah ciri dikehendaki sebagai antena boleh dipakai. Dalam projek ini, antena tekstil menggunakan bahan denim yang mempunyai $\varepsilon_r = 1.70$ dan $tan\ \delta$ = 0.085 dipilih untuk memenuhi kelayakan antena. Model antena direkabentuk menggunakan perisian CST Microwave Studio. Beberapa prototaip antena direka dan dinilai dengan bahan berbeza (fabrik *Shieldit* dan pita kuprum). Untuk pelbagai jalur, antenna dwikutub fraktal Koch direka untuk beroperasi pada frekuensi 0.915, 2.45 dan 5.8 GHz. Antena fraktal Koch telah mengurangkan sebanyak 15% daripada panjang asal antenna lurus dwikutub. Kedua-dua antena dengan bahan berlainan diperhatikan dalam jangka kehilangan kembali, jalur lebar, corak sinaran dan keberkesanan. Tiga analisis yang berbeza diuji pada antenna fractal Koch dalam keadaan lenturan, pada tubuh badan dan keadaan basah. Prestasi antena dinilai dari segi frekuensi resonan dan jalur lebar. Daripada analisis, didapati bahawa lenturan terhadap antena fraktal kuprum manusia telah mengubah secara drastik dari 0.90, 2.45 dan 5.16 GHz kepada 0.49, 1.16 dan 3.03 GHz. Penempatan antena yang sesuai pada tubuh manusia telah ditemui di dada yang berfungsi pada 0.80, 2.56 dan 5.16 GHz dan bahagian belakang yang berfungsi pada 0.88, 2.48 dan 5.8 GHz. Antena Koch fraktal pelbagai jalur mengekalkan prestasi apabila kurang 3% penyerapan air di bawah keadaan basah. Prestasi antena kuprum telah ditunjukkan lebih baik daripada fabrik Shieldit antena dari segi kehilangan kembali, corak sinaran dan keuntungan kerana pengurangan tenaga hilang daripada bahan tersebut. Walaubagaimanpun, antena *Shieldit* adalah lebih fleksibel dan tahan lama berbanding dengan antena kuprum.

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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
$\emptyset$	-	Degree of flare angle

LIST OF ABBREVIATIONS

3D	-	3-Dimension
3G	-	Third Generation
BW	-	Bandwidth
CT	-	Copper Tape
ECG	-	Electrocardiogram
FCC	-	Federation Communication Commission
GSM	-	Global System for Mobile Communications
IEEE	-	Institute of Electrical and Electronics Engineers
ISM	-	Industrial, Scientific and Medical
S11	-	Reflection coefficient
CENELEC	-	European Committee for Electrotechnical Standardization
CST	-	Computer Simulation Technology
SAR	-	Specific Absorption Rate
RF	-	Radio Frequency
PIFA	-	Planar Inverted-F antenna
GPS	-	Global Positioning System (GPS)
UMTS	-	Universal Mobile Telecommunications System
LTE	-	Long Term Evolution
DTV	-	Digital Television
CPW	-	Coplanar Waveguide
LCP	-	Liquid Crystal Polymer
RFID	-	Radio-frequency identification
UHF	-	Ultra-high frequency
SMA	-	SubMiniature version A
ICNRIP	-	International Commission on Non-Ionizing Radiation Protection

UWB	-	Ultra-Wide Band
WIFI	-	Wireless Fidelity
W	-	Watt
WIMAX	-	Worldwide Interoperability for Microwave Access
WLAN	-	Wireless Local Area Network
WBAN	-	Wireless Body Area Network
GHz	-	Giga Hertz
TM	-	Transverse Mode
DRW	-	Durable Water Resistant

CHAPTER 1

INTRODUCTION

1.1 Research Background

Wearable computer system technology has been rapidly developing in the medical, the healthcare and the military sectors since over the past few decades. The wearable system has improved quality life for the users as the main purpose by providing flexible, light-weight and mobile wearable devices that offer real-time monitoring [1], tracking location detection [2] and emergency alert information [3]. For example, the medical monitoring can widely used in the crowded hospital environment in order to collect, transfer and transmit information of all the patient's data such as location and patient's condition [4].

Generally, the wearable system is introduced as "smart clothing with sensing, displaying, transmission of information and communication" [5]. The wearable devices are equipped with multiple electronic components including power source, microcontroller, variable sensors such as temperature and ECG sensor and communication part such as an antenna. Nowadays, the researcher has been struggling to produce a multi-function wearable system with digital textile sensor, accelerometer and gyroscope to detect user's movement and posture for game activities [6]. Other researchers have been developing the wearable system with multiple sensors which consist of accelerometer and displacement sensor for real-time physical activity monitoring using Zigbee [7].

Antenna plays an important role in the wearable system which functions to transmit and receive radio signal in the wireless communication process. However, most conventional antennas are not suitable for the wearable system because the antennas have rigid structure, big size and high cost manufacturing. Therefore, textile antenna is introduced into the wearable system due to its flexibility, robustness and light weight material. The textile antenna based on the fabric material also could be integrated into the garment without disrupting the user's comfort.[8 - 9]

As concerned with this research, the material of textile antenna components is taken into consideration to design good antenna performance in term reflection coefficient, bandwidth, current distribution and efficiency. Two significant components of textile which are conducting element and substrate have been highlighted. For good characteristic of conducting element, the high conductivity of conductive material, flexible structure and homogenous sheet resistances are required [10]. There are many types of flexible conducting element which is commercialized in the market such as copper foil tape, *Shieldit* fabric, *Pure Copper Taftella* fabric and *Zelt* fabric. Many fabrics are used as antennas substrate such as flannel, polyester, fleece, cotton and felt. Choosing fabric material types will determine the antenna performance especially in terms of efficiency and bandwidth. Based on the previous research, the substrate with low permittivity and thickness will greatly influence the antenna performance [11].

Recently, the multiband antenna attracted by the designer because the antenna offers multiple frequency bands in a single antenna unit. Various designs of multiband textile antenna have been invented for the wearable system since a decade ago. There are many types of multiband textile antennas that has been designed such as 2.2 GHz and 3.0 GHz patch antenna using felt fabric [12], 2.45 GHz and 5.2 GHz Sierpenski fractal PIFA antenna using fleece substrate [13] and dual band WLAN CPW-fed monopole antenna using felt textile [14].

One of possible candidate, printed dipole antenna can offer omnidirectional pattern and reasonable gain; 2.15 dB which is suitable for wearable communication. The dipole antenna is simple, old design and widely used consists of two spread conductor which is ½ lambda in length. The omnidirectional antenna transmits and receive signal in all direction at the same plane. In free spaces, the beam width of antenna is 55^{0}. However, the limitation of dipole antenna is narrow bandwidth and backward antenna radiation. Also, compact size antenna is a challenge for the antenna designer to reduce space in the system in order to minimize the fabrication cost. The researcher had studied to miniaturize the dipole antenna using meandered line [15], Minkowski fractal structure [16] and spiral structure [17].

Wireless Body Area Network (WBAN) is a wireless wearable network system especially in the on-body communication systems for medical application. So far, no available standard is specified for medical, healthcare and military application. However, the Industrial, Scientific and Medical (ISM) band was introduced by the Federation Communication Commission (FCC) for the free use of radiofrequency on industrial, scientific and medical purposes. For the ISM band, frequencies of 0.915 GHz, 2.45 GHz and 5.8 GHz are available. The most recent communication technology has been developed for the wearable system using low-power wireless technology such as Zigbee [18], Bluetooth [19], Wi-Fi [20] and Wireless Body Area Network [21] covering at the ISM frequency band.

A dipole antenna is proposed to work at multi-frequency band for the wearable application. So, the multiband fractal dipole antennas are recommended in this work, since the antenna has simple structure, light weight and offer omnidirectional pattern. The textile antenna is designed using the denim material with permittivity, ε_r of 1.75 operating at 0.915 GHz, 2.45 GHz and 5.8 GHz. Then, fractal geometry is introduced into the antenna design to minimize the size of the antenna. The textile antenna is fabricated with different conducting material such as copper foil and *Shieldit* fabric. The antenna performance in term of gain, return loss, bandwidth and resonant frequency is evaluated to compare performances with different conducting material.

Aspect consideration of the textile antenna was evaluated such as bending, on body measurement and wetness experiment. The degradation of resonant frequency of 2.45 GHz cotton antenna performance has been reported under the bending condition due to change physical antenna structure [22]. Electromagnetic (EM) coupling effect from the human body influence the antenna performance such as input impedance, power efficiency, resonant frequency and bandwidth [23]. The placement antenna on the body needed to be studied among forearm, arm, chest, and backside to find the placement which is able to maintain the antenna performance. Other consideration, Specific Absorption Rate (SAR) in human body has been considered to ensure the EM absorption toward body follow the limitation standard to minimize potential hazard for health by EM radiation. The textile antenna is also needed to be investigated under wet condition to evaluate antenna performance with water. The water has high dielectric constant is able to change the resonant frequency and impedance bandwidth drastically [24]. According to the consideration fact, the antenna needs to be designed to operate well in all conditions.

1.2 Problem Statement

In wearable electronic, antenna plays a paramount role in optimal performance of the wearable devices. Most conventional antennas have a rigid structure, a big size and expensive material such as FR4 board, Taconic fiber glass and Roger hydrocarbon ceramic. As alternative, wearable antennas such as wired antenna [25], flexible substrate antenna [26] and film antenna [27] are introduced in making the antenna more flexible. However, users still feels not uncomfortable with the wearable antenna when involved in a certain body movement and position. Furthermore, the most wearable antennas cannot be attached to the garment. This results in demands for flexible textile antenna.

For wearable application, the textile antenna needs to radiate signal uniformly in all directions with reasonable gain for communication with base station and other devices. The suitable type of antennas for the wearable application is Planar Invented-F Antenna (PIFA) antenna [23], patch antenna [28] and dipole antenna [29] because the antennas offer omnidirectional pattern. Based on the previous research, the dipole antenna is less studied compared among the patch and (PIFA) antenna. The major limitation of dipole antenna is backward radiation into the human body because the antenna is designed without ground plane. However, Artificial Magnetic Conductor (AMC) can be integrated with the dipole antenna to avoid the backward radiation into the human body [30].

The dipole antenna is proposed as the multiband textile antenna. For the dipole antenna, the resonant frequencies are determined based on the total length of the antenna and the relative permittivity of substrate. Based on the previous studies, the length of dipole antenna becomes longer at the lower frequency. Thus, the antenna needed to miniaturize the size while maintaining good characteristic of antenna. At the same time, most of textile antennas are limited for single application only [31] and using licensed band [32]. Thus, the new design and technique are studied to miniaturize the multiband antenna using free unlicensed band.

The proximity of the human body, bending effect and wetness effect toward the antenna performance are the main challenges to be tackled for designing the textile antennas. The antenna performances have to operate well in all condition involving the placement, movement and changing body posture. Based on the previous research, the report stated that bandwidth fluctuate from 413 MHz to 440 MHz at 2.4 GHz and from 644 MHz to 570 MHz at 5.8 GHz, when dual band PIFA antenna is placed on human body [23]. Also, the resonant frequency will shift upward due to its changing U-shaped slot effective of dual band patch antenna at 1.9 GHz and 2.4 GHz under bent condition [33]. Other issue, wet antenna or antenna with high relative humidity disrupt the actual antenna performance due to the high dielectric constant of water [34]. Furthermore, special attention must be paid to the limitation of SAR in human body in order to minimize harmful effect of radio electromagnetic toward the human body [35].

1.3 Objectives of Research

This research will give a positive impact to the development of textile antenna for wearable application. The project will propose the multiband dipole textile antenna for wearable application. From previous research, the researchers just have focused in designing textile antenna with patch antenna and PIFA antenna only and testing the antenna performances under bent, wetness condition and body placement. At the same time, the multiband antenna will be operated at the three ISM bands which are 0.915 GHz, 2.45 GHz and 5.8 GHz. In term material, two types of antenna is fabricated which are using with *Shieldit* fabric for fully textile antenna and copper tape for semi textile antenna. No research related with the effect of dipole textile antenna performance on body placement, wet and bending condition has been reported. The objectives can be written as follows:

i. To design, simulate and fabricate a Fractal Koch Multiband dipole textile antenna using the denim material operating at ISM band which are 0.915 GHz, 2.45 GHz and 5.8 GHz.
ii. To evaluate fractal Koch multiband textile antenna performance with different conducting material; conventional copper tape and *Shieldit* fabric.
iii. To investigate the fractal Koch multiband textile antenna performance in bending condition, on-body measurement and wet condition.
iv. To evaluate the maximum SAR in human body from the fractal Koch multiband textile antenna.

1.4 Scope of Work

In order to achieve the objectives, several steps have been considered to accomplish the proposed textile antenna. This includes a comprehensive literature review, which study about the previous design of single, multiband and ultra-wideband textile antenna. It is important to build the basic knowledge on designing the textile antenna and identify the expected result and limitation in designing of textile antenna. Then, dipole antenna as the main element of antenna design has been highlighted. At the same time, the previous research about designing of compact dipole antenna has been reviewed. According to the main objective, the multiband fractal Koch textile antennas are proposed using the denim material operating at 0.915 GHz, 2.45 GHz and 5.8 GHz. The antenna is produced by the combination of three miniaturized fractal Koch dipole structure. The antennas with fractal Koch implementation have been discussed.

Computer Simulation Technology (CST) an electromagnetic software has been used to simulate the antenna design and analyze the antenna result performance in terms of return loss, radiation patterns, efficiency, current distribution, and other.

The characterization of denim fabric properties including permittivity and loss tangent has been determined using coaxial probe technique following the previous research [36]. The electromagnetic properties data is required before starting the simulation of antenna process. The antenna design has been optimized at 0.915 GHz, 2.45 GHz and 5.8 GHz with parameter sweeping technique using the CST software to achieve best antenna performance. From this project, the outcome from the simulation antenna result is compared to the fabricated antenna.

After the optimization process, the simulated antenna is fabricated using computerized cutting tool machine to ensure the accuracies of fabrication antenna dimension. The antenna is fabricated using two different conductive materials which are *Shieldit* fabric and copper tape to evaluate antenna performance. The measurement result of return loss, radiation pattern and gain is measured using network in the anechoic chamber. Lastly, the fabricated antenna has been measured the antenna performance such as the bandwidth and the resonant frequency under bending, wetness condition and on-body measurements. There are limited measurement equipment to investigate gain and efficiency. The significant facts of influence on bending, wetness and on body measurement have been described. The simulation of antenna toward human body is conducted to determine the maximum SAR value for each band. The SAR measurement not been conducted in this project due to the limitation of the equipment.

1.5 Thesis Outline

This thesis contains six chapters including introduction, literature review, research methodology, antenna design consideration, result and discussion and conclusion. The main objective project is designing fractal Koch multiband textile antenna using dipole structure for wearable application operating at 0.915 GHz, 2.45

GHz and 5.8 GHz. Then, the antenna are compared and analyzed between antenna using *Shieldit* fabric and copper tape. Both antennas are tested under bending and wetness condition and on-body measurement. Chapter 1 briefly describes research background of overall project, scope of research, and main objective of the project.

Chapter 2 will focus on the literature review of textile antenna such as component of textile antenna, electromagnetic properties consideration and aspect consideration of designing textile antenna. This chapter also explains the types of textile antenna design including single band, multiband and ultra-wideband application. The previous researches of designing dipole antenna as proposed antenna types are discussed. Lastly, antenna with implementation fractal Koch has been reviewed from the previous research to miniaturize the proposed multiband dipole antenna.

In Chapter 3, the research methodology of project will be explained. This chapter also explains the characterization technique for determining the permittivity and loss tangent of fabric material using coaxial probe techniques. The flow chart of overall process of designing textile antenna including simulation, fabrication, measurement and experiment is explained. Methodology of designing multiband fractal Koch antenna is described. For final stage of this chapter, the measurement setup of textile antenna investigation under bending condition, wetness condition and on-body measurement has been discussed.

Chapter 4 explains design of the multiband textile antenna for wearable application. This chapter starts with details of the proposed dipole antenna. Combination of three dipole structures will resonate at 0.915 GHz, 2.45 GHz and 5.8 GHz. This chapter continues on the implementation fractal Koch geometry in the multiband design to minimize the size of the antenna. As a final topic in this chapter, the antenna parameter including width, gap, spacing of dipole are optimized.

Chapter 5 show the simulated and measured result of fractal Koch multiband textile antenna such as return loss, radiation pattern, current distribution and gain are compared and analyzed. The measured result of textile antenna under three experiments; bending experiments, on-body measurement and wetness experiment are also discussed. Then, the maximum SAR in human body is studied. The procedure setups on all experiments are explained in this chapter. Both proposed antenna; *Shieldit* and cooper tape multiband antenna is investigated under all experiments. Chapter 6 concludes the overall project. Recommendation and future work on this project has been discussed in this last chapter.

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