DUAL BAND TEXTILE ANTENNA ON ARTIFICIAL MAGNETIC CONDUCTOR FOR ON-BODY COMMUNICATION APPLICATIONS

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DEDICATION

Specially dedicated to my beloved wife, Siti Masturah Zakeria and my children;

Muhammad Hadif Akhyar, Nur Aesha Humaira, and Muhammad Aqeel for their love

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ABSTRACT

The integration of wearable devices on human body in Wireless Body Area Network (WBAN) offers new favourable and assistances. The properties of human body causes high transmission loss in the wearable antenna. In WBAN, the antenna and the artificial magnetic conductor (AMC) is needed to be flexible and comfortable to wear. Efficient wireless networking system depends on reliable tranmission between antennas. Textile dual-band AMC is developed as a ground plane to improve wireless on-body transmission. It offers clear on-body transmission path with increased antenna' performances. The proposed wearable antennas and AMC jacket are purely textiles, which makes it convenient for wearable communication. In this thesis, the performance of single-band and dual-band textile antenna with and without dual-band AMC are studied in terms of radiation characteristic, reflection coefficient and transmission path. The antennas and AMC are designed to be operated at 2.4 GHz and 5.8 GHz. From the experiment, the characteristics of textile dipole antennas are altered when placed on the AMC sheet. The radiation characteristics and bandwidth of the antenna for both frequencies follow the AMC behavior while the gain of the antenna is increased about 4 dB. The radiation pattern of the antenna becomes directive when placed on the AMC sheet. Then, several experiments of transmission between antennas are conducted to test the reliability of the communication. Different antenna' orientation and placement are considered. A maximum gain of 15 dB is achieved when the antenna is placed in a horizontal and vertical orientation. Finally, three types of jackets which are normal, ground and AMC jackets are fabricated. The transmission between antennas on those jackets are compared. Significant transmission enhancement is observed when both antennas are placed on the AMC jacket and vice versa to when the antennas are placed on the ground jacket. It shows a 15 dB S_{21} transmission improvement compared to transmissions on the normal jacket. Moreover, the AMC jacket offers outwards directional radiation pattern from human body with high gain. In addition, the textile bending measurement is also investigated. It is found that the textile bending gave no significant effect to the antennas and AMC sheet performance. In conclusion, the dual-band textile antenna and dual-band AMC jacket are successfully developed.

ABSTRAK

Integrasi peranti boleh dipakai pada badan manusia dalam Rangkaian Kawasan Badan Tanpa Wayar (WBAN) menawarkan kelebihan dan bantuan baru. Sifat-sifat badan manusia menyebabkan kehilangan penghantaran yang tinggi dalam antenna boleh dipakai. Dalam WBAN, antenna dan pengalir magnet buatan (AMC) perlu fleksibel dan selesa untuk dipakai. Sistem rangkaian tanpa wayar yang efisyen bergantung pada penghantaran dua jalur yang boleh dipercayai antara antenna. AMC dua jalur tekstil dibangunkan sebagai satu satah bumi untuk meningkatkan penghantaran tanpa wayar pada badan. Ia menawarkan jalan penghantaran pada badan yang jelas dengan meningkatkan prestasi antenna. Antenna boleh dipakai dan AMC jaket yang dicadangkan adalah tekstil sepenuhnya, yang sesuai untuk komunikasi boleh dipakai. Dalam tesis ini, prestasi antenna tekstil satu jalur dan dua jalur dengan dan tanpa AMC dua jalur dikaji dari segi ciri-ciri radiasi, jalur pantulan dan laluan penghantaran. Antenna dan AMC direka untuk berfungsi pada 2.4 GHz dan 5.8 GHz. Dari eksperimen, ciri-ciri antenna dwikutub tekstil berubah apabila diletakkan pada helaian AMC. Ciri-ciri radiasi dan lebar jalur antenna bagi kedua-dua frekuensi mengikut tingkah laku AMC manakala gandaan antenna ditingkatkan sekitar 4 dB. Corak radiasi antenna menjadi direktif apabila diletakkan pada helaian AMC. Kemudian, beberapa eksperimen penghantaran antara antenna dilakukan untuk menguji kebolehpercayaan komunikasi. Orientasi dan letakkan antenna yang berbeza diambil kira. Gandaan maksimum 15 dB dicapai apabila antenna diletakkan dalam orientasi mengufuk dan menegak. Akhirnya, tiga jenis jaket yang biasa, bumi dan AMC jaket dibuat. Penghantaran antara antenna pada jaket-jaket tersebut dibandingkan. Peningkatan penghantaran yang ketara didapati apabila kedua-dua antenna diletakkan pada jaket AMC dan sebaliknya apabila antenna diletakkan pada jaket bumi. Ia menunjukkan peningkatan penghantaran 15 dB S_{21} berbanding penghantaran pada jaket biasa. Malah, jaket AMC menawarkan corak radiasi ke arah luar dari badan manusia dengan gandaan yang tinggi. Seterusnya, pengukuran bengkokan tekstil juga dikaji. Didapati bahawa bengkokan tekstil tidak memberikan kesan yang signifikan terhadap prestasi antena dan helaian AMC. Kesimpulannya, antena tekstil dual-band dan jaket AMC dual-band berjaya dikembangkan.

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LIST OF SYMBOLS

Z_s	-	Surface impedance
ε_r	-	Substrate permittivity
h	-	Substrate thickness
δ	-	Tangent loss
d	-	Separation distance between dipole antenna and metal surface
λ	-	Operating wavelength
Z_0	-	Characteristic impedance
ε_{eff}	-	Effective dielectric constant
Γ	-	Reflection coefficient
D	-	Directivity
f_r	-	Operating frequency
L	-	Inductance
C	-	Capacitance
W	-	Patch width
g	-	Gap between the patches
f_L	-	Lower frequency
ε_0	-	Free-space permittivity
μ_0	-	Free-space permeability
η_0	-	Free-space impedance
λ_0	-	Free-space wavelength
λ_g	-	Guided wavelength

LIST OF ABBREVIATIONS

AMC	-	Artificial Magnetic Conductor
CAD	-	Computer Aided Design
CST	-	Computer Simulation Technology
EBG	-	Electromagnetic Band Gap
ECG	-	Electrocardiogram
FSS	-	Frequency Selective Surface
FR-4	-	Flame Retardant-4
GP	-	Ground Plane
HIS	-	High Impedance Surface
IEEE	-	Institute of Electrical and Electronics Engineers
MP3	-	MPEG-1 Audio Layer-3
PEC	-	Perfect Electric Conductor
PIFA	-	Planar Inverted-F Antenna
PMC	-	Perfect Magnetic Conductor
RF	-	Radio Frequency
RL	-	Return Loss
SMA	-	Sub Miniature Version A
UMTS	-	Universal Mobile Telecommunications System
UWB	-	Ultra-Wideband
WBANs	-	Wireless Body Area Networks
WLANs	-	Wireless Local Area Network
WPANs	-	Wireless Personal Area Networks
WSANs	-	Wireless Sensor Area Networks

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CHAPTER 1

INTRODUCTION

1.1 Research Background

Body-centric wireless communication is the integration of wearable networking devices and sensors through a system of antenna, guided wave surface and transceivers for telecommunications. The electromagnetic waves for the system propagate through human body as transmission medium or path. In the system, the surface of the human body acts as transmission medium or path for electromagnetic waves.

The body-centric wireless networks (BCWN) contains of three main classes, which are communication within on the body surface known as on-body, communication from the body-surface to surroundings called as off-body, and at least one node may be implanted within the body known as in-body [1-4]. In other words, Body centric communication is the combination of Wireless Sensor Networks (WSNs), Wireless Body-Area Networks (WBANs), and Wireless Personal Area Networks (WPANs) [5-6]. Healthcare, military, space exploration and smart home are the wide range of applications that contributes this communication to be developed [7-11]. So, the improvement of the existing body centric systems is one of the purposes of this research.

An antenna is an electromagnetic transceiver; it produces an electromagnetic field from the transmitting antenna to the receiver's antenna. Hence, the efficiency of the electromagnetic communication system is determined by the performance of an antenna. An antenna that provides the good electromagnetic signal propagation close to human body is most of the requirement for on-body communication. In body centric communication, most of the antenna used is wearable antenna [12-14] due to their characteristic, which is easily worn as part of clothing. On top of that, wearable antennas are also cheap, light, and can work in a wide range of frequencies [15-16].

Over the years, the most common of the wearable antenna types is the textile antenna [17-22]. The earliest design was in the form of a helmet [23] and vest [24-25]. Generally, textiles have low dielectric constant; hence wider bandwidth. The performance of on-body antennas degrades because of human body properties. Apart from that, fabric material is easily bent, stretched and crumpled. Because of that, the antennas worn on human body may not function well. Due to disadvantages mentioned, this research will introduce artificial magnetic conductor (AMC) structure as a new approach to body centric communication.

1.2 Problem Statements

Wearable antennas have been widely used in on-body communication due to its attractive properties which are flexible and comfortable to wear. Due to the discrete properties of human body [26], performance of wearable antennas degrades significantly which results in distortion of input impedance and radiation characteristics. Furthermore, radiation that enters into the human body may effect the human health [27]. Local scattering, geometry or size of the body and body activities also affect the on-body propagation [28].

In addition, properties of human body cause the unwanted high transmission loss between antennas. An effectiveness body centric wireless networking requires good transmission between on-body antennas. The reliability of the wireless communication within human body depends on transmission between the antennas. A new technique of body centric wireless communication is introduced in order to overcome the drawbacks of wearable antennas. This technique uses waveguide structure onto sheets to be worn on human body [26, 29]. However, this AMC sheet is not purely made of textile materials.

In [162], wireless and wired communication are combined together to monitor and transfer the data between human body and control unit. Nowadays, single application or equipment is meant for many purposes. As example, a wireless healthcare device is used for monitoring and censoring human bodies. A single band antenna and AMC sheet is not enough to ensure that the equipment is functioning properly. Its communication system needs more antennas for transmitting and receiving data and continuously.

New studies are being carried out to overcome the drawbacks This research proposes to develop dual-band textile antenna with dual-band textile dual-band textile AMC jacket. In this study, a conformal jacket that acts as a transmission medium is proposed. The combination of AMC jacket and wearable antennas provides better on-body wave propagation.

1.3 Research Objectives

This research is primarily concerned to develop a dual-band AMC jacket for on-body communication system that is made of textile material, which is appropriate for conformity in wearable communication. A new method of minimizing on-body transmission losses is presented by introducing the AMC sheet as a ground plane for on-body antennas. The AMC sheet produces high gain as well as reduces the backward radiation towards human body.

Thus, the main research objectives are outlined as follows:

i. To develop single band and dual-band textile diamond dipole antennas at 2.4 GHz and 5.8 GHz. The antennas have wider bandwidth compare to common dipole antenna.
ii. To develop dual-band textile AMC jacket at 2.4 GHz and 5.8 GHz. The AMC jacket is purely textile, made of fleece fabric and Shieldit fabric.
iii. To measure the performance analysis of transmission between dual-band textile antennas on dual-band textile AMC jacket.

1.4 Scope of Research

The scope began with gathering information, review and study the literature of related topics such as concept of AMC sheet in body centric communication, the theory and design of antenna and AMC and review the usage of textile materials in antenna and AMC in wireless. This work aimed the antenna and AMC to be operated in WLAN frequency band (2.4 GHz and 5.8 GHz). The antennas and AMC jacket are purely made of fleece fabrics. They should have to be flexible, wearable and comfort to wear. Then, the performance of the antennas is compared with and without AMC sheet. Lastly the transmission between antennas is measured on AMC jacket with horizontal and vertical polarization.

1.5 Key Contribution

Single band and dual-band diamond dipole textile antennas have been proposed in this research for wearable application. Dual-band AMC sheet was implemented to have directive radiation pattern and higher gain.

The proposed dual-band AMC jacket with dual-band diamond dipole antenna were enhancement concept of body centric communication. The AMC jacket can minimize the effect human body gives off towards the antenna's performance because of smaller backward radiation. The electromagnetic waves of the antenna communicate with each other through the AMC structure by providing an independent path for the antenna to propagate. Both antenna and AMC jacket were made of textile material; fleece fabric as the substrate and Shieldit fabric as the conducting element. The fully textile design is flexible and suitable for wearable application.

As conclusion, dual-band textile antenna and dual-band AMC jacket which operate at 2.45 GHz and 5.8 GHz have been successfully developed in this study. The prototypes are fully fabric, suitable for healthcare, military and personal entertainment. The designs have been presented in several conferences and published in journals.

1.6 Thesis Outline

The main theme of this thesis is textile antenna and textile AMC jacket.as well as the evaluation of antennas' transmission characteristic in body centric environment. Chapter 1 introduces the background of the research, problem statements, research benefits, objectives and scope of research.

Chapter 2 discusses on overview of body centric wireless communication as well as the concept and application of AMC structure in on-body environment. Besides that, theory of wearable dipole antenna and AMC surface are reviewed in this chapter too.

In Chapter 3, the methodology of the research is presented. Initially, since this research revolves within textile materials for the antennas and AMC sheet, the methodology involved in the textile material characterization is explored. The design, simulation, fabrication and measurements processes are also discussed in detail.

Chapter 4 presents on the design of single-band and dual-band diamond dipole antennas. The chapter starts with the performance of two single-band diamond dipole and dual-band diamond dipole antenna. Detailed simulation and measurement results will be discussed in details.

Chapter 5 investigates the performance of the antennas and AMC structure. The performance of the antennas with and without AMC sheet are compared. Then, the experiment of transmission of the antennas on AMC jacket is conducted.

Finally, Chapter 6 summarizes this thesis with the research findings. Future research works are also suggested.

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