DESIGN AND EVALUATION OF WEARABLE TEXTILE ANTENNAS BACKED BY AMC FOR LOCALIZATION APPLICATION

by

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LIST OF ABBREVIATIONS

AMC	Artificial Magnetic Conductor
AUT	Antenna Under Test
CST	Computer Simulation Technology
dB	Decibel
FBR	Front to Back Ratio
FSS	Frequency Selective Surface
EBG	Electromagnetic Band Gap
GHz	Mega Hertz
MHz	Mega Hertz
mm	Millimeter
PEC	Perfect Electric Conductor
PMC	Perfect Magnetic Conductor
RF	Radio Frequency
SAR	Specific Absorption Rate

LIST OF SYMBOLS

Θ	Theta
Π	Pi
Ω	Ohm
Δ	Variance
ε_{eff}	Effective Permittivity
ε_r	Relative Permittivity
c	Speed of Light
f_r	Resonant Frequency
tan-δ	Loss Tangent
λ	Wavelength
φ	Phi

Rekabentuk Dan Penilaian Antena Tekstil Bolehpakai Tersandar AMC Untuk Aplikasi Penentuan Lokasi

ABSTRAK

Kajian ini memberi tumpuan kepada pembangunan beberapa antena bersaiz padat yang baru dan sesuai untuk aplikasi penentuan lokasi dalam format boleh pakai. Bagi memastikan bahawa antena-antena ini mampu beroperasi dengan penyahtalaan yang minimum disebabkan penggunaannya di atas badan, antena-antena ini telah direka dengan tiga strategi, pertamanya adalah untuk memastikan saiznya yang padat, keduanya, melebarkan jalur operasinya dan akhirnya, seboleh-bolehnya direka dengan satah bumi penuh di bahagian belakang strukturnya. Walaubagaimanapun, pelaksanaan teknik-teknik pengecilan saiz dan pelebaran jalur biasanya menghasilkan degradasi gandaan, manakala perlaksanaan satah bumi penuh mengehadkan lebar jalur antena. Kaedah yang cekap untuk mengatasi kedua-duanya ialah penggunaan kepelbagaian teknik pengecilan saiz dan pelebaran jalur seperti slot dan satah konduktor magnetik tiruan (AMC). Satah AMC ini dibentuk menggunakan jujukan sel unit berdasarkan tampalan segiempat untuk beroperasi dalam mod-mod jalur tunggal atau jalur aneka. Bagi memastikan kepadatan saiz dan operasi aneka jalur, slot cincin berbentuk segiempat disepadukan ke dalam sel-sel unit berbentuk tampalan segiempat sebelum digabungkan dengan antena. Tiga reka bentuk antena baru dicadangkan dalam disertasi ini; suatu antena tekstil dwi-polarisasi dan dwi-jalur dengan satah AMC (Antena 1), suatu antena berasaskan mikrostrip tekstil jalur lebar (Antena 2 (a)) dan antena tekstil jalur lebar dengan cincin AMC (Antena 2 (b). Selain perbezaan topologi, antena ini juga dikendalikan dalam mod frekuensi yang berbeza (dwi-jalur dan jalur lebar), dan telah direka bentuk menggunakan jenis tekstil yang berbeza. Walaupun asalnya merupakan antena berjalur sempit, Antena 2 (a) dan Antena 2 (b) yang dihasilkan berasaskan topologi mikrostrip adalah berjalur lebar dan bersaiz padat hasil daripada gabungan beberapa teknik pelebaran jalur dan pengecilan saiz. Antena 1 menunjukkan gandaan 1.98 dB dengan lebar jalur 7.6 % pada 1.575 GHz. Sementara itu, pada 2.45 GHz ia menunjukkan 1.94 dB gandaan dengan lebar jalur sebanyak 5.5 %. Ia juga menunjukkan 9 % nisbah paksi untuk polarisasi bulat pada 1.575 GHz. Antena 2 (a) memperoleh gandaan dan lebar jalur masing-masing 3.5 dB dan 51 %. Akhirnya, kombinasi satah AMC dan antena planar berjalur lebar ini telah meningkatkan lebar jalur keseluruhan, serta mengecilkan saiz antena. Antena-antena ini berpotensi sebagai antena yang berkesan bagi aplikasi penentuan lokasi pintar yang boleh digunakan di persekitaran dalam dan luar bangunan.
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Design and Evaluation of Wearable Textile Antennas Backed by AMC for Localization Application

ABSTRACT

This research focuses on the development of several new compact antennas suitable for localization application in a wearable format. To ensure that these antennas are able to operate with minimal detuning caused when placed on body, they have been designed with three strategies, first is to ensure its size compactness, secondly, a wide bandwidth and finally, to adapt, wherever possible, a full rear ground plane. However, the implementation of miniaturization techniques typically results in gain degradation, whereas the implementation of the full ground plane limits antenna bandwidth. One efficient method to simultaneously overcome both is the use of multiple miniaturization and broadbanding techniques such as slots and artificial magnetic conductor (AMC) plane. This AMC plane is formed using an array of unit cells based on the square patch to operate in single or multiband modes. To enable size compactness and multiband operation, square-shaped ring slots are integrated onto the square unit cells prior to its combined use with antennas. Three new antenna designs are proposed in this dissertation; a dual-band dual-polarized textile antenna with AMC plane (Antenna 1), a wideband textile microstrip-based antenna (Antenna 2(a)) and wideband textile antenna with ring slotted AMC (Antenna 2(b)). Besides differences in topology, these antennas also operated in different frequency modes (dual-band and wideband), and are being designed on different textile materials. Despite being inherently narrowband, the microstrip-based Antenna 2(a) and Antenna 2(b) are designed to be wideband and compact by combining several broadbanding and miniaturization techniques. Antenna 1 obtained a gain of 1.98 dB with a bandwidth of 7.6% at 1.575 GHz. Meanwhile, at 2.45 GHz it showed 1.94 dB of gain with 5.5 % of bandwidth. It also indicated 9 % of axial ratio for circular polarization at 1.575 GHz. Meanwhile, Antenna 2(a) obtained a realized gain and bandwidth of 3.5 dB and 51 %, respectively. Finally, the combination of AMC plane and this wideband planar antenna enhanced the overall bandwidth and decreased the antenna size. These antennas indicated great potential as effective antennas for application in smart wearable localization in indoor and outdoor environments.

CHAPTER 1 : INTRODUCTION

1.1 Introduction

In recent years, wearable textile antenna has gained attention due to the attractiveness of integrating wireless capability into clothing for several body-worn applications. Several attractive applications for localization applications includes Cospas-Sarsat for search and rescue, Global Positioning System (GPS), Wireless Local Area Network (WLAN), Wireless Body Area Network (WBAN) and etc.

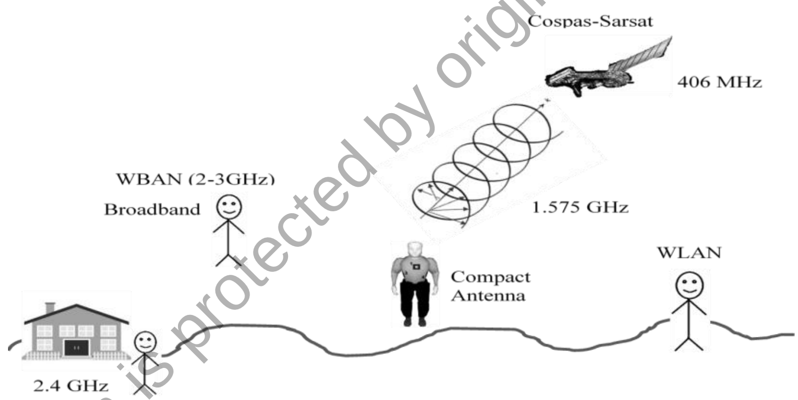

Figure 1.1: Different scenarios in wearable localization applications

Figure 1.1 shows the different situations in localization applications. It is shown that the Cospas-Sarsat system operating at 406 MHz is capable of receiving distress alert and location information for search and rescue purposes. This service is used worldwide for maritime, aviation and land users in distress via a beacon. Meanwhile, circularly polarized antennas are typically required for satellite-based location tracking such as the GPS. However, GPS signals are less capable to be received indoors, and WLAN signals are typically used for indoor localization. Thus, there exists a need for an antenna with dual-band and dual-polarization, which is proposed in this work. This single antenna operates at 1.575 GHz and 2.45 GHz with circular- and linear polarization, respectively, for GPS and WLAN localization. Finally, a compact and wideband wearable antenna also has been designed to operate between 2 and 3 GHz. Due to its operation in a broad spectrum, it can also be effectively used in various localization applications, with minimal effect due to the body detuning. Despite being designed using different techniques to operate at different frequencies, two antennas in this research are aimed at providing a compact and robust solution against body detuning using flexible and comfortable textile materials for wearable localization application.

Textile antennas are an ideal solution due to their comfort, light weight, high flexibility and ease of integration with clothes. Generally, the antenna for localization applications is operated in specific frequency bands such as L-band, S-band, X-band and etc. Each of the operating bands has its own advantages and disadvantages. For example, operations in the lower frequency bands are capable of longer range propagation due to its wavelength in comparison to operate in higher frequency bands. However, antennas operating in the lower frequency bands will be larger in size due to their required electrical length.

Microstrip patch antennas are a suitable topology for such applications due to its planar form and the readily-available rear ground plane. This functions as a shielding to minimize electromagnetic wave absorption in the human body. Besides that, microstrip antennas are increasingly integrated with additional features such as beam-steering, while maintaining their operating frequency. Moreover, these antennas can also be designed to be more compact using miniaturization techniques, which will be presented in this work.

Recent implementations of engineered material such as artificial magnetic conductor (AMC) onto the microstrip patch antenna have been validated to be capable of miniaturizing their sizes (Upadhyaya, T. K., et al, 2012). This results in space efficiency for smaller on-body areas. Besides AMCs, high permittivity or permeability substrates can also be used to reduce the wavelength in the substrates. However, a high impedance mismatch is expected, which will lead to low efficiency for the miniaturized antenna. Nonetheless, the use of AMCs provides moderate permittivity or permeability to facilitate high miniaturization factor while minimizing impedance mismatch. The aim of this work is to design wearable textile antennas based on several planar topologies and integrate it with these engineered material to achieve wider bandwidths, compact sizes and acceptable gains.

1.2 Problem Statement

The development of wearable antennas is challenging due to its requirement to ensure that they are able to operate with minimal degradation when used on body. The most popular and simplest method in avoiding detuning caused by users' body is to minimize the electromagnetic interaction between the radiator and body is by adapting planar topologies with existing rear ground plane. Despite being one of the most suitable antenna topologies, microstrip patch antennas are intrinsically narrow in bandwidth. Hence, methods of broadbanding techniques are important to overcome this problem.

There is also a need to combine multiband functionality in these antennas to support wireless localization capabilities in indoor and outdoor environments using a single wearable device. Besides that, lower frequency bands used for emergency search and rescue situations may also result in an inherent antenna size. Thus, methods of miniaturizing the antenna are of crucial importance, while maintaining sufficient antenna gain over most of the body to ensure wireless link reliability. Besides overcoming these challenges in textile antennas, any proposed wearable antennas need to operate well in planar and deformed conditions, in free space and when applied on body.

1.3 Objectives

The main objectives of this research are as follows:

i. To design, develop and fabricate new wearable antennas based on several planar topologies with multiband frequencies of 1.575 GHz, 2.45 GHz and from 2 to 3 GHz.

ii. To overcome the inherent antenna size at low frequencies and bandwidth limitations resulting from the use of full ground plane using multiple miniaturization/broadbanding techniques and AMC plane.

iii. To validate the performance of the proposed textile antennas in planar and bent conditions when operated in free space and on body.

1.4 Scope of Work

The scope of this research is demonstrated as in Figure 1.2.

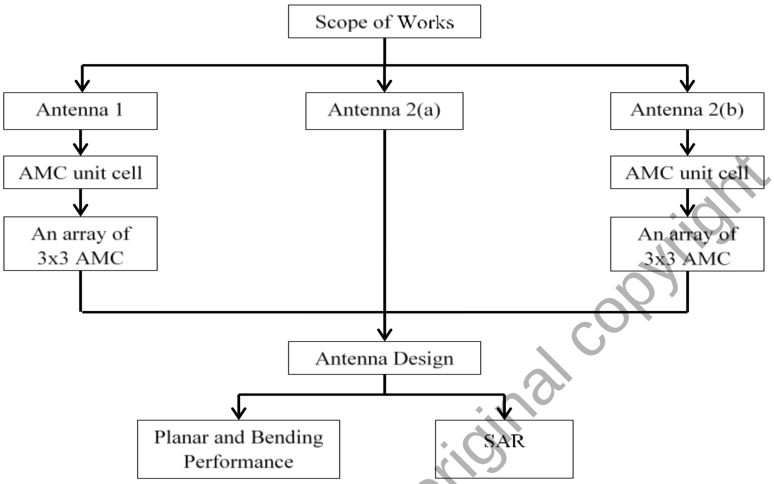

Figure 1.2: Scope of work.

This work needs to pass several stages fulfill the objectives of this research. The stages are divided into four stages as follows.

Stage 1: Design Review

Revision and analysis is performed to identify the most suitable wearable antenna topology and materials to be implemented for localization purposes. The most potential topology has been identified is based on the microstrip patch antenna and dipole antenna. Techniques which are used to enhance their bandwidths and enable further size compactness are also studied. Besides that, a study of metamaterials with a special focus on artificial magnetic conductor unit cells is also performed. The aim is to result in an innovative and compact antenna design with the capability of reducing backward radiation towards the human user, increase bandwidth and enhance gain will be prioritized.

Stage 2: Initial Antenna and AMC Design

To determine the initial dimensions of the patch antenna, analytical calculations are performed based well-known equations in calculating the width and length of a microstrip patch antenna. Besides that, such analytical calculation is also extended to determine an initial dimension of the unit cell of the artificial magnetic conductor. The characteristics of the substrate such as its permittivity and thickness highly affect the size of the patch antenna and artificial magnetic conductor. The simulation has been performed in Computer Simulation Technology (CST) Studio Suite software based on these analytical dimensions. These dimensions are then further optimized using the same software.

Stage 3: Material Properties and Antenna Simulation in CST

Once suitable textile materials for the project have been identified for the AMC and microstrip antenna, their properties are then measured and defined in CST for further use in the design process. In this work, the textile antennas are designed using Felt and Kevlar as the substrate, while the conductors are made using ShieldIt Super conductive textile. Upon its completion, the different topologies of the wearable textile antennas are designed using various miniaturization and broadbanding techniques to alleviate the body detuning issue. Optimization are performed using parametric study in this software for both the antenna, AMC and when both structures are integrated.

Stage 4: Fabrication and Result Analysis

The optimized antennas prototypes are then fabricated using suitable textile/flexible materials in this stage. Measurements will be performed on all antenna prototypes using specialized equipment available in the Advanced Communication Engineering (ACE) Centre of Excellence, Universiti Malaysia Perlis (UniMAP). The measured results of the reflection coefficient, radiation pattern and gain will be analyzed and compared with simulations.

1.5 Contribution of the Thesis

The contributions of this thesis are listed as follows:

i. Two main types of textile antennas have been designed using different topologies and implemented using a combination of miniaturization and broadbanding techniques for localization application.

ii. Antenna 1 is designed based on a patch topology which has been designed to enable dual band and dual (linear and circular) polarization using a single radiator. It is integrated with an AMC plane to minimize potential back radiation and improve its performance in terms of gain.

iii. Antenna 2 is designed based on the microstrip topology, has been implemented with AMC to reduce back radiation and improve bandwidth. The AMC's contribution is benchmarked against a similar microstrip-based topology without the AMC plane.

1.6 Thesis Outline

This thesis is organized into five chapters. Chapter 1 introduces the thesis with its problem statements, objectives, scope of work, contributions and thesis outline. In Chapter 2, a brief description about microstrip patch antenna and textile materials is presented. Besides that, the past research on the textile antennas focusing on localization applications is also reviewed, besides the past research on AMC-based wearable textile antennas.

Chapter 3 presents the systematic steps of modelling the wearable textile antennas. The methodology in the optimization and fabrication process is also explained in detail with the aid of equations and illustrations. The simulation and measurement setups in modelling and the textile antennas are also explained in this chapter. Finally, the three new wearable textile antennas for localization application are presented in detail. They include the dipole- and microstrip-based topologies, and two types of AMC unit cells, which are designed to operate in the 1.575 GHz, 2.45 GHz and the wideband antenna operating from 2 to 3 GHz.

Chapter 4 presents the simulation and measurement results of the three antenna designs. They include their performance in terms of reflection coefficient, bandwidth, radiation patterns, gain, efficiency and Specific Absorption Rate. Besides being evaluated in free space, their performances are also studied under bent conditions with different radii to quantify the level of changes when implemented on body. Finally, the conclusion of the thesis is drawn in Chapter 5. Several suggestions for future work are also highlighted in this chapter.

CHAPTER 2 : LITERATURE REVIEW

2.1 Introduction

In line with the main objective of this dissertation, which is to design and develop new and compact wearable antennas for localization applications, it is important that the critical aspects are addressed. In this chapter, subtopics such as microstrip patch antennas, wearable antennas, localization technology, artificial magnetic conductor and polarization will be reviewed, besides their state-of-the art.

2.2 Wearable Antennas for Localization Application

A wearable textile antenna is an antenna that can be worn or integrated into clothing for tracking and navigation, communication, mobile computing and public safety. This is mainly due to the advancements in innovative materials to be applied as antennas. For example, in (Hertleer, C., et al, 2007), the wearable antenna is designed and integrated into fire fighters' protective clothing. The conductive textiles which have been used for shielding from electromagnetic radiation in the past now are now being adapted as materials for textile antenna design. These textiles are conventionally made from polymer threads or conductive metals which are combined with ordinary fabric threads. Its structure is almost similar with the conventional fabric that can be sewn for daily clothing.

The introduction of wireless protocols for personal area networks and body area networks (PANs and BANs) which operates at 2.45 GHz triggered the emergence of