BEAM-SWITCHABLE TEXTILE ANTENNA FOR WIRELESS BODY AREA NETWORKS (WBAN)

by

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"You simply will not be the same person two months from now after consciously giving thanks each day for the abundance that exists in your life. And you will have set in motion an ancient spiritual law: the more you have and are grateful for, the more will be given you." -*Sarah Ban Breathnach*-

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ABSTRAK

Kerja kajian di dalam tesis ini menumpukan kepada kawalan radiasi tekstil antena berfungsi kepada aplikasi rangkaian kawasan badan tanpa wayar (*WBAN).* Idea kawalan radiasi tekstil antena ini membantu untuk penghasilan antena yang lebih kecil, penjimatan kos penghasilan dan lebih fleksibiliti. Kawalan radiasi antenna sangat praktikal dalam perbangunan pesat sistem komunikasi tanpa wayar. Kelebihan yang ada pada kawalan radiasi tekstil antena adalah dapat membantu dalam mengelakkan masalah berkaitan penyamaran saluran yang ditanggung oleh pergerakan atau perubahan arah pemakai. Tesis ini memperkenalkan satu kawalan radiasi tekstil antena *(BSTA)* yang unik dengan keupayaan kawalan radiasi menggunakan frekuensi radio *(RF)* PIN diod litar pincangan sebagai mekanisma kawalan. *BSTA* merupakan usaha pertama yang memperkenalkan antena kawalan perambatan radiasi yang boleh dipakai dengan mengeksploitasi pelekat berasaskan perak untuk penyediaan penyambungan antara tekstil dan litar RF. Empat PIN diod suis di diintegrasi ke shildit super *BSTA* yang simetri. *BSTA* berupaya mencapai kecodongan radiasi ke arah ±16° dengan puncak pengarahan simulasi dan diukur masing-masing 6.8 dBi dan 6.69 dBi. Antena ini mampu mengekalkan galangan masukan 50 Ω pada frekuensi 2.45 GHz tanpa menggunakan pengubah suku gelombang tambahan.Dengan dimensi 88 x 88 mm^2, ia adalah cukup kompak untuk disepadukan dengan pakaian untuk aplikasi *WBAN*. Berdasarkan penilaian awal kadar penyerapan tertentu *SAR,* penyelidikan ini mengesahkan bahawa *BSTA* adalah selamat kepada tubuh manusia dengan hasil keputusan simulasi *SAR* kurang daripada 1.6 W/kg dan 2 W/kg untuk setiap 1g and 10g isipadu tisu di bahagian badan tertentu berdasarkan peraturan *ICNIRP*. Dengan semua keupayaan ditunjukkan dan dibincangkan, BSTA mempunyai potensi besar untuk merealisasikan antena untuk pakaian pintar yang baru.

ABSTRACT

The research work in this dissertation focuses on beam-switchable textile antenna for wireless body area network (WBAN) application. The idea of beam-switchable textile antenna helps to reduce the antenna size and more flexible. Beam-switchable antenna is useful in the rapid growth of the wireless communication system. The advantage of beam-switchable antenna is to avoid the associated signal equalization problems that are incurred as the wearer moves or turns. This dissertation proposed a novel beam-switchable textile antenna (BSTA) with reconfigurable ability which uses Radio Frequency (RF) PIN diodes biasing circuit as the switching mechanism. BSTA is the first effort in realizing a combination of such beam-switching feature onto a wearable radiator by exploiting silver loaded epoxy adhesive to provide a solderless connection between conductive textiles and the RF circuits. Four PIN diode switches are integrated into shieldit super of symmetrical BSTA designed. The BSTA is capable to achieve beam steering ±16° with peak simulated and measured directivities of 6.8 dBi and 6.69 dBi, respectively. The antenna maintains input impedance approximately 50 Ω at 2.45 GHz without the use of additional quarter wavelength transformers. With dimension of 88 x 88 mm^2, it is compact enough to be integrated in clothing for WBAN applications. Based on preliminary assessment of specific absorption rate (SAR) results, this research confirms that BSTA is safe to the human being where the simulation SAR result is less than 1.6 W/kg and 2 W/kg for 1g and 10g mass of tissues correspondingly at particular body parts based on ICNIRP regulation. With all capabilities demonstrated and discussed, the BSTA antenna has big potential in realizing a new smart garment antenna.

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LIST OF SYMBOLS & ABBREVIATIONS

θ	Theta
Γ	Reflection Coefficient
Π	Pi
Ω	Ohm
η	Efficiency
ε	Permittivity
Δ	Loss Tangent
CAD	Computer Aided Design
CST	Computer Simulation Technology
dB	Decibel
dBm	Decibel of Measured power referenced to 1 mille watt (mW)
GHz	Giga Hertz
ICNIRP	International Commission on Non-Ionizing Radiation Protection
ISM	Industrial, Scientific and Medical
km	Kilometer
mm	Millimeter

PAN	Personal Area Network
PCPTF	Pure Copper Polyester Taffeta Fabric
RF	Radio Frequency
SAR	Specific Absorption Rate
SNR	Signal Noise Ratio
VSWR	Voltage Standing Wave Ratio
WBAN	Wireless Body Area Network
WLAN	Wireless Local Area Network

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CHAPTER 1

INTRODUCTION

1.1 Introduction

Nowadays, microstrip antenna is among the popular types of antenna used by the researcher. Modern wireless communication systems demand antenna designs with light weight, small size, high frequency operation, and good transmission efficiency. In such a scenario, microstrip antenna offers many unique and attractive properties such as low profile, light weight, compact, conformable structure and easy to fabricate (D. Misman et al., 2007; D. Misman et al., 2008). In past few decades, microstrip antenna has been widely used in radio systems for various applications such as Bluetooth technology.

Conventionally, microstrip antenna used material type of FR4, which is not flexible. Such material does not fulfill the flexibility requirement to be used as the wearable on-body antenna. In that case, a separate bulky device has to be located on a suitable location of the user body such as leg, hip or thigh and a belt might be required to hold the antenna. In contrast, facilitated with wearable and flexible material such as electronic textiles (e-textiles), a new type of microstrip antenna is developed in this

dissertation where the main features of wearable antenna are light and flexible. Moreover, such antenna could be sewed together with the cloth of the user. The principal requirement for wearable antennas is the use of flexible materials for ease of integration into clothing (A. M. Mantash, A. -C. Tarot, S.Collardey, & K Mahdjoubi, 2012; M. A. R. Osman, M. K. A.Rahim, N. A.Samsuri, H. A. M. Salim, & M. F.Ali, 2011; N. H. M. Rais, 2009). With the advancements and availability of various flexible materials, it is now possible to realize such implementation of on-body antenna.

Recent works on on-body antenna are mainly focused on the implementation of directional antenna or omni-directional antenna. However, in practice with the mobility of a user, such antenna will fail to maintain a good signal reception. Various factors such as gain, polarization and directivity will affect the signal reception of this wearable antenna. In this kind of scenario, a reconfigurable antenna could be a good solution where, the antenna could reconfigure its beam, polarization and gain to sustain good reception. In past few decades, reconfigurable antenna has attracted much attention in wireless communication systems such as cellular-radio system, airplane radar, smart weapons protection and point-to-point propagation. Electronic beam-forming with RF switching can be used to enhance spectral efficiency as well as reduces the problems associated with multipath propagation. Beam switching can adjust its pattern so that the main beam always points to particular angle. However, the development of this reconfigurable antenna is mainly focused on inflexible material such as FR4 as mentioned earlier. In this dissertation, a comprehensive treatment will be given on the possibility to develop the reconfigurable antenna using flexible material.

The aim of this project is to design a wearable antenna with reconfigurable scheme. In order to enable reconfigurable ability, a beam-forming circuit needed to be embedded on textile antenna. Hence, utilization of silver loaded epoxy adhesive has been discovered to provide a solderless connection between embedded beam-forming circuit and the e-textiles.

The antenna is designed using Computer Simulation Technology (CST) Microwave Studio Suite software. The proposed switchable-beam textile antenna fabricated with a substrate made of Felt with permittivity and thickness is 1.22 and 2 mm respectively. ShieldIt super with conductivity of 5.57×10^5 S/m and thickness of 0.15 mm deployed as conductive textile (E-textile). The fabricated antenna will be measured and compared with the simulation result to prove the novel wearable antenna is capable to switch its beam through certain configuration of RF PIN diode.

1.2 Problem Statement

The development of on-body textile antenna application is still in its infancy, mainly delimited by on body- detuning. Additionally, in a body-worn antenna implementation, one needs to be not only concerned with the peak directivity offered by the antennas chosen, but also how this coverage is distributed around the body (P. J. Soh, G. A. E. Vandenbosch, S. L. Ooi, & M. R. N. Husna, 2011). Operationally, it is important to maintain good antenna directivity (dBi) over most of the whole body to help in avoiding problems with excellent directivity (dBi) over some regions while having very deep nulls in other regions and the associated signal equalization problems that are incurred as the wearer moves or turns. Reconfigurable or switchable technology

might be one of the solution as it can control radiation patterns according to the movement of users. However, integration of RF biasing circuit components with the textile require investigation to define suitable materials as the soldering iron could not be deployed on wearable textile antenna. Manual stripping technique are invented by (Sang-Jun & Chang-Won, 2011) needed three antenna design to realize reconfigurable-beam wearable antenna. The main challenges in dissertation is to realize single switchable-beam wearable antenna with intergration RF switches on antenna itself for WBAN application.

1.3 Objective

The main aim of the research work presented in the thesis is to investigates and analyze the possibility of introducing reliable reconfigurable scheme on wearable antenna. The main objectives of the study include:

i. To design and evaluate a single wearable beam-switching antenna using conductive textiles.
ii. To implement suitable materials that capable to intergrate the RF switches itself on single wearable beam-switching antenna.
iii. To investigate the reliability and effect of the new beam-switchable textile antenna when operating on a human body.

1.4 Scope of work

The scope of this research consists of several stages to achieve the objectives of this project. The stages are divided into five stages as follows:

Stage 1: Literature Review

Revision and analyze previous research related to wearable textile antenna and reconfigurable antenna to generate new ideas on how to improve their previous works. An inventive antenna design with the capability of wearable, flexible and reconfigurable beam design will be prioritized.

Stage 2: Analytical Calculation

In order to determine dimension of patch wearable antenna, analytical calculations are carried out based on basic equation of microstrip patch antenna. Based on the microstrip patch antenna , SAR equation is analyzed as well.

Stage 3: Simulation antenna design and optimization

The initial project is started by identifying suitable material for wearable antenna in terms of flexibility and wearable ability. Then, a single patch wearable antenna is designed followed by beam-switching textile antenna. All simulation assisted by CST software. In this stage, beam-forming integrated circuit on simulation using copper strip line is presented. Optimization has been conducted to obtain antenna performance results such as reflection coefficient $S_{11,}$ gain and directivity.

Stage 4: Fabrication and Measurement

Fabrication of prototype wearable antenna using ShieldIt Super as electronic textile (E-Textile) and Felt as substrate is carried out at this stage. The beam-forming circuit is attached on wearable antenna using silver loaded epoxy adhesive. All prototypes are tested and measured in Antenna and Microwave lab (Amrellab) in Universiti Malaysia Perlis (UniMAP).

Stage 5: Assessment of specific absorption rate (SAR)

Wearable antenna is significantly related with specific absorption rate (SAR) analysis. SAR analysis could investigate on-body, in-body and off-body systems. The simulation on-body is done to detect the effect of radiation from the proposed wearable antenna towards human body. Analyses of SAR results ensured the beam switchable textile antenna is safe to human being and environment.

1.5 List of Contributions

The main contributions of the research work presented in this thesis include:

i. Developed a novel single novel switchable-beam textile antenna with beam-steering tilt angle ±16° at theta 0° and 90° respectively.
ii. Deploying a silver loaded epoxy to intergrate the RF switches on single wearable beam-switching antenna itself.
iii. Providing preliminary analysis of switchable-beam textile antenna on human body through Specific Absorption Rate (SAR) results is ≤ 1.6 for 1g and ≤2 for 10g respectively.

1.6 Thesis Outline

This thesis is organized into five chapters. It starts with first chapter consists of introduction, problem statements, objectives, scopes of the project, thesis outline and contributions. In Chapter 2, a review of wearable antenna, wearable material and the reconfigurable scheme on wearable antenna are included. It provides an introduction and general review of microstrip antenna, concept of wearable antenna and reconfigurable antenna.

Chapter 3 described details on the methodology to complete this research works. The methodology covers the design specifications, design process and design flow chart of reconfigurable wearable antenna. The antenna specifications are discussed details on the targeted antenna performance of achieving beam-switchable textile antenna. Besides that, the antenna must be ensured to reconfigure main beam of a stable S_{11} with proposed RF switches technique. Moreover, the design process covered the optimizing process, fabrication process and measurement setup. The flow chart of the overall project is explained in the subchapter of Chapter 3.

A novel beam-steering textile antenna (BSTA) designs are presented in Chapter 4. The parameter studies are conducted to produce a novel beam-steering textile antenna. The investigation of this antenna are carried out by simulations and measurements. The SAR analyses are presented as the safety precaution where the SAR values must not surpassed the limit level provided by ICNIRP guidelines: IEEE C95.1 : 1999 is 1.6 W/kg for a 1g averaging mass and IEEE C95.1 : 2005 is 2 W/kg in a 10g

averaging mass. Comparison of BSTA's antenna location influence the level of SAR also presented in this chapter. Finally, conclusion and future work will be drawn in Chapter 5.