DEVELOPMENT OF WEARABLE PATCH ANTENNAS USING RUBBER SUBSTRATE FOR WBAN APPLICATIONS

BY

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ABSTRACT

The flexibility in designing the wearable microstrip patch antenna is essential for Wireless Body Area Network (WBAN) applications. The shortcomings of the wearable antenna are due to variations in characteristics once the dielectric substrate is squeezed or expanded along the outer or inner surface. In bending conditions, the overall performances in flexible antenna could be decreased. Thus, the performance should subsequently improve in designing flexible antennas. This research mainly focused on designing the microstrip patch antennas with rubber substrate as a dielectric material. Computer Simulation Technology (CST) software used for antenna simulation and analysis. We developed four types of antennas on rubber substrate to study their performances in return loss, gain, radiation efficiency, etc. Initially, the microstrip patch antenna was designed with and without defected ground structure (DGS) applied on rubber substrate. Then, we designed a coplanar waveguide (CPW) monopole antenna for single-band and multiband applications. For the DGS antenna, the reflection coefficient of -37.33 dB, the bandwidth of 4.16% (at -10 dB impedance), the antenna gain increased by 7.5%, and the voltage standing wave ratio (VSWR) value was 1.03 with the resonant frequency at the ISM band has been attained. Meanwhile, the CPW antenna reduced the overall antenna thickness (two layers) and achieved single-band and multiband applications at 2.45 GHz and 3.65 GHz. Focusing on antenna bandwidth and radiation efficiency, CPW antenna (single band) achieved the 22.16% bandwidth and around 90% of radiation efficiency. The antenna gain has improved from 3.18 dBi (without DGS) to 4.26 dBi (CPW antenna for multiband). Subsequently, we fabricated the best performance antenna, a CPW antenna for a single band using the screen-printing technique. The return loss obtained from the experiment was -22 dB, slightly different from the simulation. The VSWR value was 1.22, which was almost near to the simulation (at 1.06). This antenna can further improve by enhancing the CPW features.

خلاصة البحث

تعد المرونة في تصميم هوائي التصحيح الصغير القابل للارتداء أمرًا ضروريًا لتطبيقات شبكة منطقة الجسم اللاسلكية (WBAN). ترجع أوجه القصور في الهوائي القابل للارتداء إلى الاختلافات في الخصائص بمجرد ضغط الركيزة العازلة للكهرباء أو توسيعها على طول السطح الخارجي أو الداخلي. في ظروف الانحناء، يمكن تقليل الأداء الكلي للهوائي المرن. وبالتالي، يجب تحسين الأداء لاحقًا في تصميم الهوائيات المرنة. ركز هذا البحث بشكل أساسي على تصميم هوائيات التصحيح microstrip مع الركيزة المطاطية كمادة عازلة للكهرباء. برنامج تكنولوجيا المحاكاة الحاسوبية (CST) المستخدم لمحاكاة الهوائي وتحليله. لقد طورنا أربعة أنواع من الهوائيات على الركيزة المطاطية لدراسة أدائها في خسارة العودة ، والكسب ، وكفاءة الإشعاع، وما إلى ذلك في البداية، تم تصميم هوائي التصحيح microstrip مع وبدون هيكل أرضي معيب (DGS) مطبق على الركيزة المطاطية. بعد ذلك، قمنا بتصميم هوائي أحادي القطب للدليل الموجي متحد المستوى (CPW) للتطبيقات أحادية النطاق ومتعددة النطاقات. بالنسبة لهوائي DGS، كان معامل الانعكاس -37.33 ديسيبل، وعرض النطاق الترددي 4.16٪ ميجاهرتز (بمقاومة -10 ديسيبل)، وزاد كسب الهوائي بنسبة 7.5٪، وكانت قيمة نسبة الموجة الدائمة للجهد (VSWR) 1.03 مع تردد الطنين في نطاق ISM. وفي الوقت نفسه ، خفض هوائي CPW السماكة الكلية للهوائي (طبقتان) وحقق تطبيقات أحادية النطاق ومتعددة النطاقات عند 2.45 جيجاهرتز و 3.65 جيجاهرتز. مع التركيز على عرض النطاق الترددي للهوائي وكفاءة الإشعاع، حقق هوائي CPW (نطاق واحد) عرض النطاق الترددي 22.16٪ ميجاهرتز وحوالي 90 ٪ من كفاءة الإشعاع. تحسن كسب الهوائي من 3.18 ديسيبل (بدون DGS) إلى 4.26 ديسيبل (هوائي CPW للنطاقات المتعددة). بعد ذلك، قمنا بتصنيع أفضل هوائي أداء، وهو هوائي CPW لنطاق واحد باستخدام تقنية طباعة الشاشة. كانت خسارة العودة التي تم الحصول عليها من التجربة -22 ديسيبل، وهي تختلف قليلاً عن المحاكاة. كانت قيمة VSWR 1.22، والتي كانت قريبة تقريبًا من المحاكاة (عند 1.06). يمكن تحسين هذا الهوائي من خلال تحسين ميزات CPW.

APPROVAL PAGE

I certify that I have supervised and read this study and that in my opinion, it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a thesis for the degree of Master of Science (Electronics Engineering).

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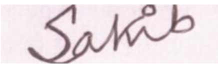
DECLARATION

I hereby declare that this thesis is the result of my own investigations, except where otherwise stated. I also declare that it has not been previously or concurrently submitted as a whole for any other degrees at IIUM or other institutions.

Nazmus Sakib



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This thesis is dedicated to my parents (Engr. Alamgir Hossain Maishan & Salina Hossain) for laying the foundation of what I turned out to be in life.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS

εr	Dielectric constant
L_{eff}	Effective length
f	Frequency
f_H	Higher frequency
L_i	Inset fed Length
L	Length
$tan\ \delta$	Loss Tangent
f_L	Lower frequency
W_p	Patch width
L_p	Patch length
Q	Quality factor
f_r	Resonant frequency
h	Substrate height
c	Speed of light
L_s	Slot length
S	Slot distance
W_s	Slot width
W_f	Width of the feedline
W	Width

LIST OF ABBREVIATIONS

AMC	Artificial Magnetic Conductor
BW	Bandwidth
CB	Carbon Black
CPW	Coplanar Waveguide
CST	Computer Simulation Technology
DGS	Defected Ground Structure
FDTD	Finite Difference Time Domain
IoT	Internet of Things
ISM	Industrial, Scientific, and Medical
MNDT	Microwave Non-Destructive Technique
NBR	Nitrile Butadiene
PDMS	Polydimethylsiloxane
RF	Radio Frequency
RL	Return Loss
SAR	Specific Absorption Rate
UHF	Ultra-High Frequency
VSWR	Voltage Standing Wave Ratio
WLAN	Wireless Local Area Network
WBAN	Wireless Body Area Network

CHAPTER ONE

INTRODUCTION

1.1 RESEARCH BACKGROUND

Flexibility in the wearable antenna is an essential part of Wireless Body Area Network (WBAN) applications, such as human movement monitoring, health monitoring, blood pressure monitoring, heartbeat monitoring, and so on. Flexible electronics is a technology that gives a certain reliable chance in rigid electronic devices to be flexible during operation. The flexible wearable antenna is currently inserted as a lightweight component designed at a resonant frequency that does not diminish after bending, twisting, or stretching. Due to the lightweight and simple processing, most of the applications are developed by designing a microstrip antenna in the present world. The rubber material would be used as a flexible substrate that can bend during body movement (Kurian et al., 2014).

A wireless body area network (WBAN) usually involves the thin, lightweight, and miniaturized antenna dimensions with the capacities of wireless communication in close proximity to the human body. The proposed flexible antenna will work at (2.4-2.5) GHz ISM band which is a narrow band with the center frequency is 2.45 GHz. The microstrip antenna is recommended as the best candidate for a lightweight antenna because it is very simple to produce that compared with others. The antenna system should not affect the human body in WBAN applications while it is placed on human skin. The proposed antenna should be low profile and flexible due to the bending of the human body. Because of its wide applications, many researchers keep developing flexible antennas. Different flexible substrates were used in the development of the flexible antenna including polymers, microfluidics, paper, plastic, rubber, etc. In this project, rubber material was used because of the good antenna characteristics especially the flexibility of the antenna. The mechanical features of rubber make it a product candidate in this respect. After deformation, it will retreat to its original proportions spontaneously (Kurian et al., 2014).

1.2 PROBLEM STATEMENT

In body area network applications, flexible wearable antennas improve the antenna performances such as return loss, voltage standing wave ratio (VSWR), gain, directivity, radiation efficiency, and surface current. Wearable antennas are more rigid and less flexible due to their higher thickness. In the case of a flexible antenna, it is not well-performing when the dielectric is stretched or compressed along its inner or outer surface. Some other research used polydimethylsiloxane (PDMS), Textile, Synthetic, Teflon as dielectric material in implementing DGS and CPW method. However, it carries some difficulties such as manufacturing complexity, high cost, poor electrical performance (relative permittivity), and limited applications that are to be improved. The suitable dielectric material in antenna design is essential to improve overall antenna performances, especially in return loss, VSWR, and antenna gain.

1.3 RESEARCH OBJECTIVES

The research tried to accomplish the following goals:

i. To design microstrip patch antenna with DGS and without DGS, CPW antenna for single band and multiband applications on rubber substrate for WBAN applications using CST microwave studio.

ii. To fabricate the antennas using the screen-printing technique.

iii. To validate the performance analysis with S_{11} parameter is around -30 dB and VSWR near 1 of the designed antennas.

1.4 RESEARCH METHODOLOGY

In designing a microstrip antenna, several crucial parameters such as VSWR, gain, bandwidth, return loss, directivity, surface current, and radiation efficiency are needed to be studied and identified. The parameters are calculated using mathematical equations to develop a microstrip patch antenna. Optimization of antenna dimensions is done through CST optimizer and the research conducting methodology flow chart is shown in Figure 1.1.

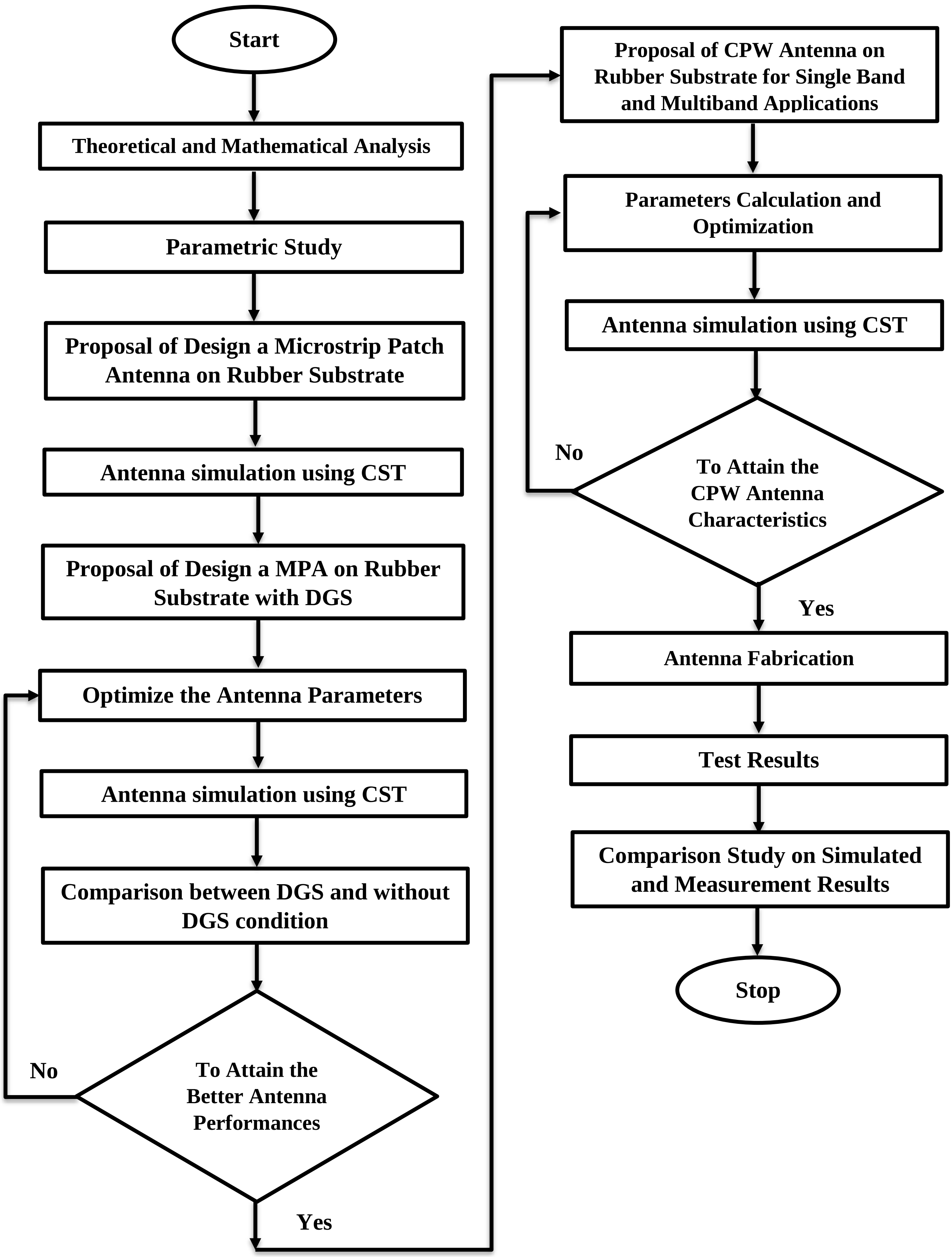

Figure 1. 1. Methodology Flowchart

1.5 RESEARCH SCOPE

The highlight of this research is to design a flexible wearable microstrip patch antenna with DGS, without DGS, and CPW antennas for a single band and multiband applications on rubber substrate that operates in WBAN applications. The antenna prototype fabricated using the screen-printing technique for CPW antenna with a single-band application using dielectric rubber substrate. The experimental results validated the simulation outcomes, and the performance analysis achieved as return loss around -30 dB, VSWR approximate to 1 of the designed antennas. However, this research did not consider specific absorption rate (SAR) calculation, body phantom with effect on body environment.

1.6 THESIS OUTLINE

The thesis is outlined as follows: Chapter one presents the introduction of the thesis. It provides a general overview of the study, followed by the problem statement. It provides a general overview of the study, followed by the problem statement. The three key points are mentioned as research objectives. Chapter two discusses the literature review on previous works that have been done in a flexible antenna. It also includes the mathematical equations for calculating the antenna dimensions. Moreover, it also presents the various methods to achieve better outcomes of the antenna. Finally, the comparison study presents compared with the past few year works. Chapter three discusses the methodology, the simulation software, the proposed designs, and the parametric studies. Chapter four explains the simulated results for the S_{11}, VSWR, radiation patterns (polar form), radiation efficiency, directivity, surface current, and antenna gain. In this chapter, the fabrication process also describes an experimental setup in this discussion using a vector network analyzer (VNA). This chapter concludes by comparing the measured and simulated results as return loss, VSWR of each antenna.

Finally, the remarks and suggestions for potential research are given in Chapter five.

CHAPTER TWO

LITERATURE REVIEW

2.1 INTRODUCTION

Antenna is a vital communication component in wireless signal propagation system. Data can be transmitted by propagating signals in airspace from one side to another using antennas. Health monitoring, physical activity monitoring, pressure control and even athletic applications, navigation, wearable electronics are generally recognized in the medical system. At this time, the wearable patch antenna provides an essential contribution in the implementations of the Wireless Body Area Network (WBAN).

The robust, lightweight, and mechanical strains are the major characteristics of flexible antennas. The main attribute of the flexible antenna is versatile, lightweight, resilient, and mechanically strength. To replace this existing rigid substrate has been taken into design a flexible antenna that was an alternative approach. The basic concept of the flexible antenna that the copper layer attach with the flexible substrate and the conductivity must be retained same as it bends. The flexible substrates such as polymer, rubber, microfluidics/liquid, paper, plastic, PDMS have been reported by many researchers (Kurian et al., 2014). As a flexibility consideration, the rubber which is a natural polymer is preferred. Meanwhile, the rubber is a great selection as flexible substrate based on mechanical properties to design an antenna. Eventually, it can be treated into various shapes and can be placed with metal strip or mounting plates (Awang et al., 2016)

The wireless body area network (WBAN) is usually involved in terms of low energy, compressed, low loss, confined or unconfined, lightweight devices with the