

**DEVELOPMENT OF WEARABLE PATCH ANTENNAS
USING RUBBER SUBSTRATE FOR WBAN
APPLICATIONS**

BY

NAZMUS SAKIB

A thesis submitted in fulfilment of the requirement for the
degree of Master of Science (Electronics Engineering)

**Kulliyyah of Engineering
International Islamic University Malaysia**

JULY 2021

ABSTRACT

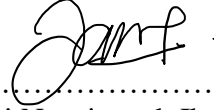
The flexibility in designing the wearable microstrip patch antenna is essential for Wireless Body Area Network (WBAN) applications. The shortcomings of the wearable antenna are due to variations in characteristics once the dielectric substrate is squeezed or expanded along the outer or inner surface. 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).



.....
Siti Noorjannah Ibrahim
Supervisor

.....
Muhammad Ibn Ibrahimy
Co-Supervisor

I certify that I have 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).

.....
Norun Farihah Abdul Malek
Internal Examiner

.....
Fauziahanim Che Seman
External Examiner

This thesis was submitted to the Department of Electrical and Computer Engineering and is accepted as a fulfilment of the requirement for the degree of Master of Science (Electronics Engineering)

.....
Mohamed Hadi Habaebi
Head, Department of Electrical
and Computer Engineering

This thesis was submitted to the Kulliyah of Engineering and is accepted as a fulfilment of the requirement for the degree of Master of Science (Electronics Engineering)

.....
Sany Izan Ihsan
Dean, Kulliyah of Engineering

DECLARATION

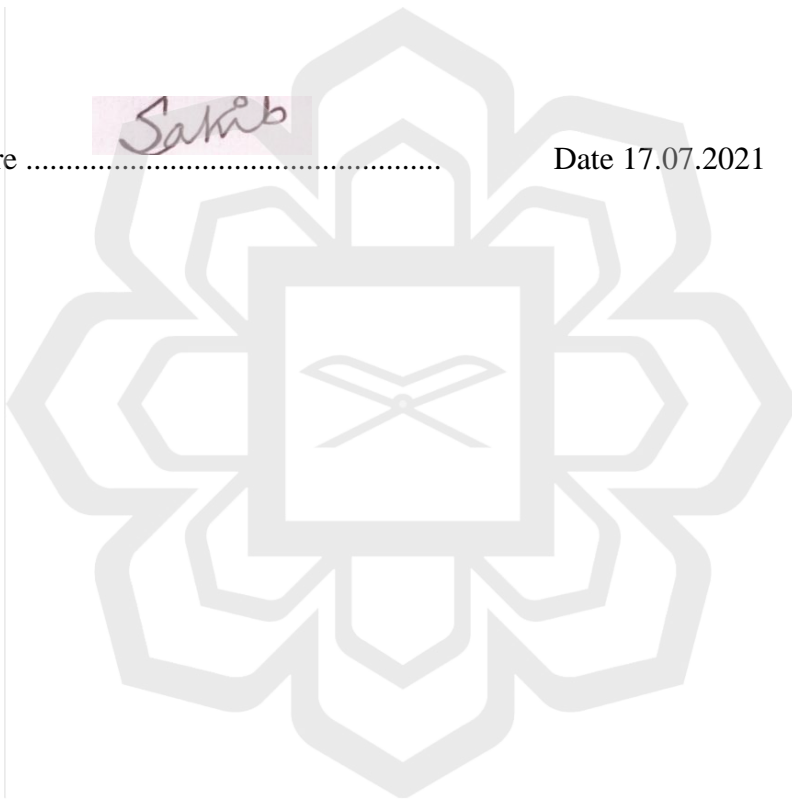
I hereby declare that this thesis is the result of my own investigations, except where otherwise stated. I also declare that it has not been previously or concurrently submitted as a whole for any other degrees at IIUM or other institutions.

Nazmus Sakib

Signature

Sakib

Date 17.07.2021



INTERNATIONAL ISLAMIC UNIVERSITY MALAYSIA

**DECLARATION OF COPYRIGHT AND AFFIRMATION OF
FAIR USE OF UNPUBLISHED RESEARCH**

**DEVELOPMENT OF WEARABLE PATCH ANTENNAS USING
RUBBER SUBSTRATE FOR WBAN APPLICATIONS**

I declare that the copyright holders of this thesis are jointly owned by the student and IUM.

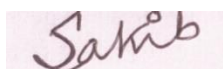
Copyright © 2021 Nazmus Sakib and International Islamic University Malaysia. All rights reserved.

No part of this unpublished research may be reproduced, stored in a retrieval system, or transmitted, in any form or by any means, electronic, mechanical, photocopying, recording or otherwise without prior written permission of the copyright holder except as provided below.

1. Any material contained in or derived from this unpublished research may be used by others in their writing with due acknowledgement.
1. IUM or its library will have the right to make and transmit copies (print or electronic) for institutional and academic purposes.
2. The IUM library will have the right to make, store in a retrieved system and supply copies of this unpublished research if requested by other universities and research libraries.

By signing this form, I acknowledged that I have read and understand the IUM Intellectual Property Right and Commercialization policy.


Affirmed by Nazmus Sakib



.....
Signature

17.07.2021

.....
Date



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.

ACKNOWLEDGMENTS

All glory is due to Allah, the Almighty, whose Grace and Mercies have been with me throughout the duration of my programme. Although, it has been tasking, His Mercies and Blessings on me ease the herculean task of completing this thesis.

I am most indebted to my supervisor, Assoc. Prof. Dr Siti Noorjannah Ibrahim, whose enduring disposition, kindness, promptitude, thoroughness and friendship have facilitated the successful completion of my work. I put on record and appreciate her detailed comments, useful suggestions and inspiring queries which have considerably improved this thesis. Her brilliant grasp of the aim and content of this work led to her insightful comments, suggestions and queries which helped me a great deal. Despite her commitments, she took time to listen and attend to me whenever requested. The moral support she extended to me is in no doubt a boost that helped in building and writing the draft of this research work. I am also grateful to my co-supervisor, Prof. Dr. Muhammad Ibn Ibrahimy, whose support and cooperation contributed to the outcome of this work.

Dr Nik Intan Nik Ismail supported to prepare the rubber samples at Rubber Research Institute Malaysia (RRIM), Dr. Intan Helina Hasan helped to do the screen printing at the Institute of Advanced Technology (ITMA), UPM, Malaysia. I also thanks to Dr. Nurul Huda Abd Rahman, she helped me to do the rubber material test (permittivity and loss tangent) at UiTM, Shah Alam, Malaysia.

Lastly, my gratitude goes to my elder brother Engr. Tarik bin Alamgir; for his kind support, proofreading and guidance.

Once again, we glorify Allah for His endless mercy on us, one of which is enabling us to successfully round off the efforts of writing this thesis. Alhamdulillah

TABLE OF CONTENTS

Abstract.....	ii
خلاصة البحث.....	iii
Approval Page.....	iv
Declaration.....	v
Copyright Page.....	vi
Acknowledgments.....	viii
Table of Contents.....	ix
List of Tables.....	xi
List of Figures.....	xii
List of Symbols.....	xvi
List of Abbreviations.....	xvii
CHAPTER ONE: INTRODUCTION.....	1
1.1 Research Background.....	1
1.2 Problem Statement.....	2
1.3 Research Objectives.....	2
1.4 Research Methodology.....	3
1.5 Research Scope.....	5
1.6 Thesis Outline.....	5
CHAPTER TWO: LITERATURE REVIEW.....	7
2.1 Introduction.....	7
2.2 Patch Antenna.....	8
2.3 Flexible Antenna.....	12
2.4 Patch Antenna with Rubber Substrate.....	14
2.5 Patch Antenna with DGS.....	33
2.6 CPW Antenna for Single Band Application.....	35
2.7 CPW Antenna for Multiband Applications.....	39
2.8 Comparison Between Previous Works.....	43
2.9 Summary.....	44
CHAPTER THREE: METHODOLOGY.....	45
3.1 Introduction.....	45
3.2 Methodology Theory.....	46
3.3 CST Microwave Studio (CST MWS).....	46
3.4 Flow of Designed Antennas.....	47
3.4.1 Patch Antenna on Rubber Substrate (Without DGS).....	48
3.4.2 Patch Antenna on Rubber Substrate with DGS.....	50
3.4.3 CPW Antenna on Rubber Substrate for Single Band Application.....	52
3.4.3.1 Bending condition.....	55
3.4.4 CPW Antenna on Rubber Substrate for Multi Band Applications.....	57
3.5 Fabrication.....	61
3.6 Summary.....	68

CHAPTER FOUR: RESULTS AND ANALYSIS	69
4.1 Introduction.....	69
4.2 Patch Antenna without DGS.....	69
4.3 Patch Antenna with DGS.....	74
4.4 The Comparison Between The Antenna at DGS and Without DGS Conditions.....	78
4.5 CPW Antenna For Single Band Application.....	79
4.5.1 Parametric Study of The CPW Antenna for Single Band Application.....	84
4.5.1.1 Effects of Inset Fed (L_i).....	85
4.5.1.2 Effects of The Slot Width (W_{s3}/W_{s4}).....	86
4.5.1.3 Effects of Substrate Height (h).....	87
4.5.2 Effect of Bending Condition.....	88
4.5.3 Comparison with Previous Works.....	90
4.6 CPW Antenna For Multi Band Applications.....	91
4.6.1 Comparison with Other Works.....	97
4.7 Comparison Between Simulation and Measurement Results.....	98
4.7.1 Return Loss at Flat Condition.....	98
4.7.2 VSWR at Flat Condition.....	99
4.7.3 Bending Effect (E-plane and H-plane).....	100
4.8 Summary.....	102
CHAPTER FIVE: CONCLUSION AND RECOMMENDATIONS	103
5.1 Conclusion.....	103
5.2 Future Recommendations.....	105
REFERENCES	106
LIST OF PUBLICATIONS	109

LIST OF TABLES

Table 2. 1.	Performance comparison of previous works	43
Table 3. 1.	Dimensions of the designed antenna	49
Table 3. 2.	DGS dimensions of the antenna	51
Table 3. 3.	The dimensions of the proposed antenna	54
Table 3. 4.	Dimensions of the proposed antenna	60
Table 4. 1.	The comparison between DGS and without DGS conditions	79
Table 4. 2.	Results of comparison between flat and bending conditions on return loss, bandwidth, and Q factor	89
Table 4. 3.	Comparison between radiation characteristics simulated for flat and bending conditions	89
Table 4. 4.	Comparative study on different natures and proposed antenna design	90
Table 4. 5.	Comparison between benchmarking papers and proposed work	97

LIST OF FIGURES

Figure 1. 1.	Methodology Flowchart	4
Figure 2. 1.	Structure of rectangular microstrip patch antenna	9
Figure 2. 2.	Different shape of microstrip patch elements	11
Figure 2. 3.	Geometry and dimensions (a) top view of monopole antenna, (b) bottom view of monopole antenna, and (c) (S_{11}) reflection coefficient	12
Figure 2. 4.	(a) top view of the EBG structure, and (b) metallic backing view of the EBG structure	13
Figure 2. 5.	Front and back view of the antenna	15
Figure 2. 6.	(a) Hot press process, (b) Prototype antenna	16
Figure 2. 7.	The simulated and measured results of the return loss at flat condition	16
Figure 2. 8.	Bending angles (E-plane and H-plane)	17
Figure 2. 9.	Return Loss (H-plane and E-plane)	18
Figure 2. 10.	(a) 3D model with connector, (b) Top and bottom views of the antenna structure	19
Figure 2. 11.	Geometrical model of designed antenna placed on (a) Three-layer tissue model (b) Homogeneous model	21
Figure 2. 12.	The magnitude curve of reflection coefficient in free space	21
Figure 2. 13.	(a) Samples of rubber, (b) Antenna top view	23
Figure 2. 14.	(a) Return loss (using natural rubber), (b) VSWR	24
Figure 2. 15.	The top view of the antenna	25
Figure 2. 16.	Geometry of Antenna	26
Figure 2. 17.	Return loss for different thicknesses of substrate	27
Figure 2. 18.	Return loss for different metal thicknesses	28

Figure 2. 19.	Return loss for different metal thicknesses	29
Figure 2. 20.	The flexible antenna with SSR substrate and antenna dimensions	30
Figure 2. 21.	The layout of the proposed antenna	31
Figure 2. 22.	The layout of the proposed flexible antenna (Antenna 5)	32
Figure 2. 23.	The return loss of the proposed flexible antennas (Ant 1-Ant 5)	33
Figure 2. 24.	The layout of patch antenna on Taconic TLX-8 substrate with DGS	34
Figure 2. 25.	The return loss of patch antenna on TLX-8 substrate with DGS	35
Figure 2. 26.	The layout of the CPW antenna, (a) Fed square ring, and (b) Fed square annular slot	36
Figure 2. 27.	The return loss of the CPW antenna, (a) Fed square ring, and (b) Fed square annular slot	37
Figure 2. 28.	The layout of the proposed antenna	38
Figure 2. 29.	The return loss of the proposed antenna	39
Figure 2. 30.	The layout of the proposed CPW antenna	40
Figure 2. 31.	The comparison of return loss with three correlative antennas	41
Figure 2. 32.	The layout of the quad band microstrip patch antenna	42
Figure 2. 33.	The return loss of the quad band microstrip patch antenna	42
Figure 3. 1.	Block diagram of the designed antennas	48
Figure 3. 2.	The layout of the designed antenna	49
Figure 3. 3	The layout of the patch antenna with DGS	51
Figure 3. 4.	The layout of the CPW monopole antenna	52
Figure 3. 5.	The evolution stages of the CPW monopole antenna (Ant1-Ant5)	53
Figure 3. 6.	The bending angle at 60° (degree) of the CPW antenna	56
Figure 3. 7.	Evolution stages of proposed antenna (Ant. 1- Ant. 4)	57
Figure 3. 8.	The layout with dimensions of the proposed antenna	59

Figure 3. 9.	Rubber samples (collected from RRIM)	62
Figure 3. 10.	Rubber characteristics test (Specially loss tangent and permittivity)	63
Figure 3. 11.	Fabrication process of screen printing	64
Figure 3. 12.	Stencil / Mesh	64
Figure 3. 13.	Paste formulation (a) mixing process, and (b) ultrasonic chamber	65
Figure 3. 14.	Screen printing (a) auto squeegeeing machine for printing and	65
Figure 3. 15.	Structural view of printed antenna	66
Figure 3. 16.	Structural view of the fabricated antenna	66
Figure 3. 17.	Antenna measurement by VNA	67
Figure 3. 18.	The block diagram of VNA setup	67
Figure 4. 1.	The return loss of the patch antenna on rubber substrate	70
Figure 4. 2.	VSWR of the patch antenna on rubber substrate	70
Figure 4. 3.	Three-dimensional radiation pattern for patch antenna on rubber substrate (without DGS)	71
Figure 4. 4.	Radiation pattern (polar form) for patch antenna (without DGS)	72
Figure 4. 5.	Surface current of the patch antenna (Without DGS)	73
Figure 4. 6.	Radiation efficiency of the patch antenna at normal (without DGS) condition	73
Figure 4. 7.	The return loss of the patch antenna with DGS condition	74
Figure 4. 8.	The VSWR of the patch antenna with DGS condition	74
Figure 4. 9.	The radiation pattern in polar form of the patch antenna with DGS condition	75
Figure 4. 10.	The surface current of the patch antenna at DGS condition	76
Figure 4. 11.	The radiation efficiency of the patch antenna at DGS condition	77
Figure 4. 12.	The gain of the patch antenna on DGS condition	77
Figure 4. 13.	Return loss (S11) of the CPW antenna (Antenna 4)	79

Figure 4. 14.	VSWR of the CPW antenna (Antenna 1- Antenna 4)	80
Figure 4. 15.	The radiation pattern (3D) of the CPW antenna at Antenna 4	81
Figure 4. 16.	(a) The realized gain of the CPW antenna, and (b) The radiation pattern (polar form) of the CPW antenna at Ant. 4	82
Figure 4. 17.	(a) The surface current of proposed antenna at Ant. 4, (b) The radiation efficiency of the proposed antenna at Ant. 4	84
Figure 4. 18.	The comparison of the return loss (Antenna 1 - Antenna 4)	85
Figure 4. 19.	Effect on the variation of the value of inset fed length	86
Figure 4. 20.	Effect of the variation on the width of slots at reflection coefficient	87
Figure 4. 21.	Effect of the variation on the substrate height	88
Figure 4. 22.	The return loss (S_{11}) at the bending conditions	89
Figure 4. 23.	Combination of the (S_{11}) with proposed ant.4	91
Figure 4. 24.	VSWR of proposed antenna	92
Figure 4. 25.	3D radiation pattern of proposed antenna at Ant. 4	93
Figure 4. 26.	Realized Gain at the proposed antenna	93
Figure 4. 27.	Radiation pattern at 2D of antenna	94
Figure 4. 28.	The surface current of proposed antenna at Ant. 4	95
Figure 4. 29.	The radiation efficiency of the proposed antenna at Ant. 4	96
Figure 4. 30.	Combine return loss of the simulated and measured antenna	99
Figure 4. 31.	Combine VSWR of the simulated and measured antenna	100
Figure 4. 32.	The combine outputs of the antenna at bending condition (E-plane)	101
Figure 4. 33.	The combine outputs of the antenna at bending condition (H-plane)	102

LIST OF SYMBOLS

ϵ_r	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
MNDR	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

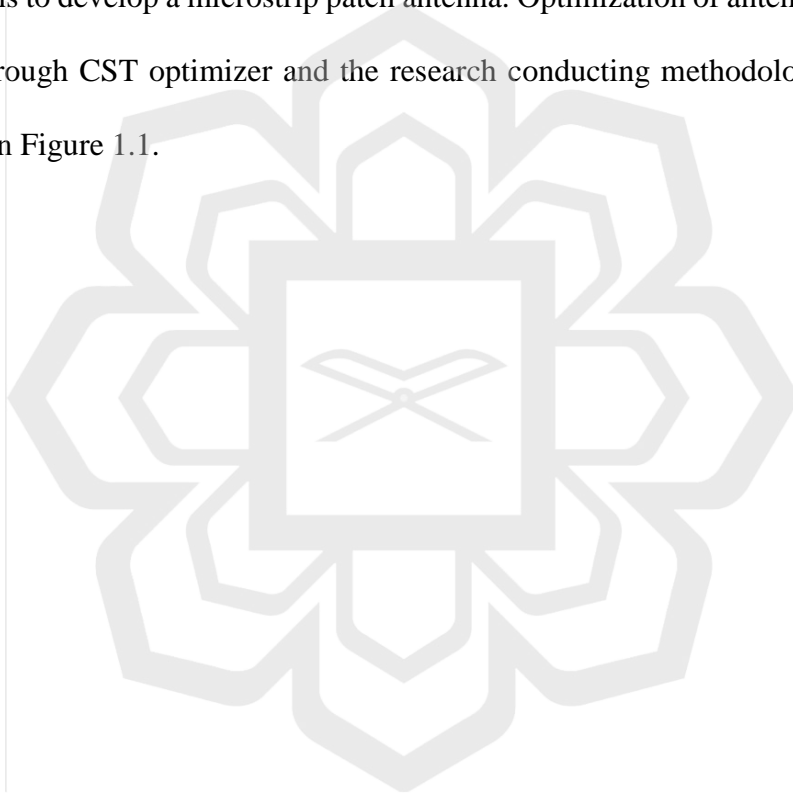
The research tried to accomplish the following goals:

- 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.



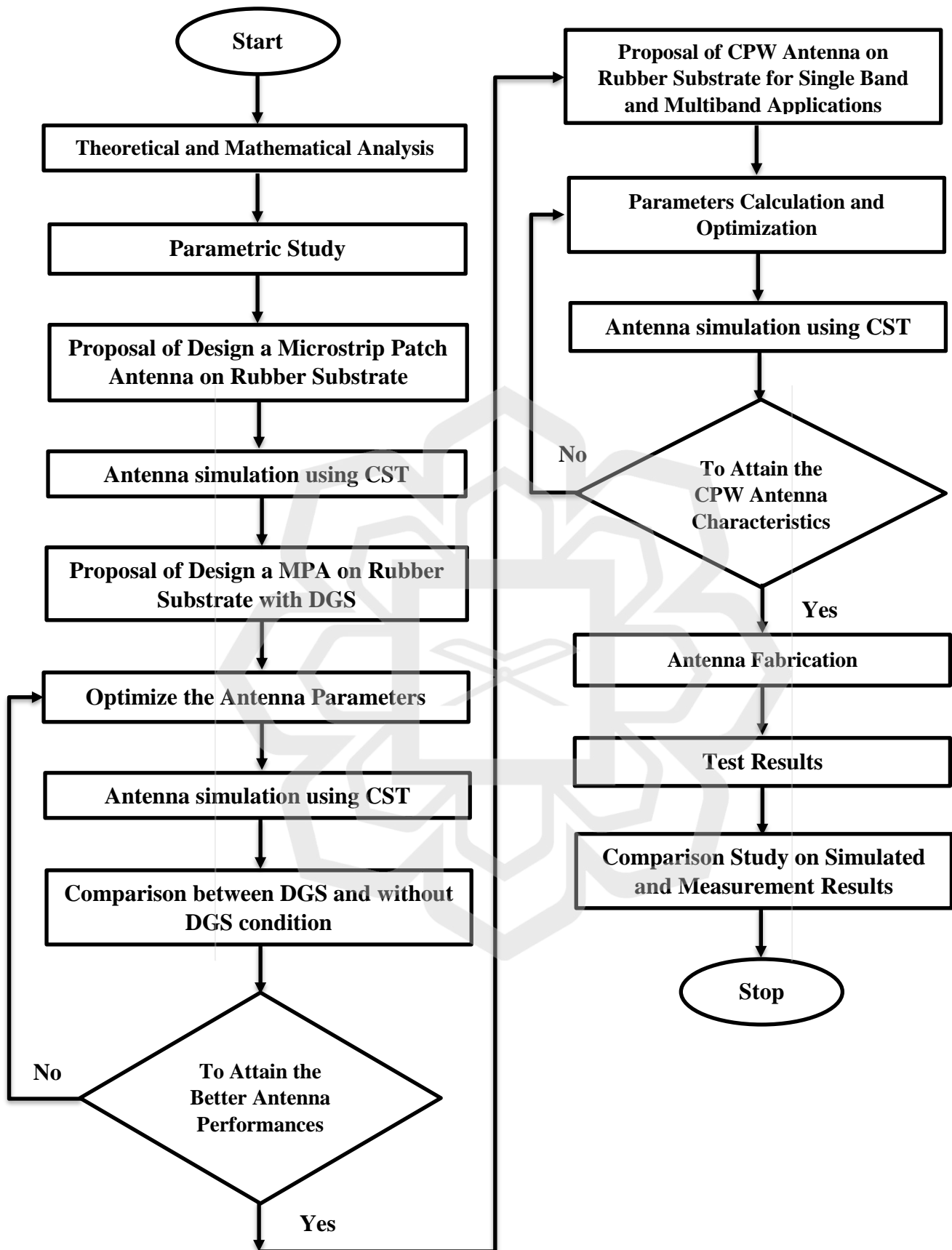


Figure 1. 1. Methodology Flowchart

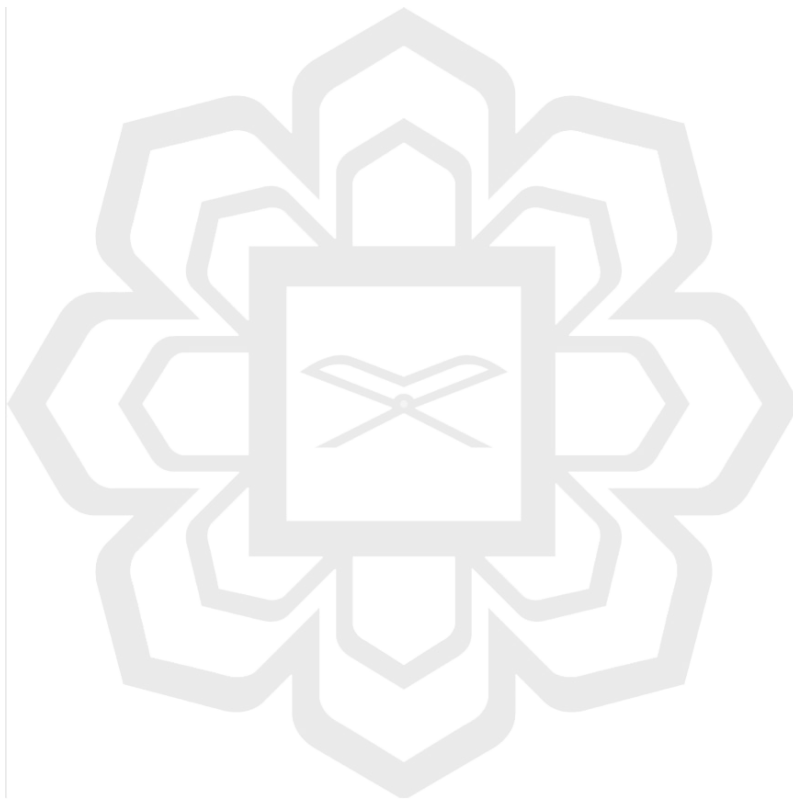
1.5 RESEARCH SCOPE

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