



**ANALYSIS OF WEARABLE ANTENNA USING
ELECTROMAGNETIC BAND GAP UNDER BENDING
CONDITIONS**

AINI NOOR LIANA BINTI AZMI

**MASTER OF SCIENCE IN ELECTRONIC
ENGINEERING**

2018



Faculty of Electronic and Computer Engineering

**ANALYSIS OF WEARABLE ANTENNA USING
ELECTROMAGNETIC BAND GAP UNDER BENDING
CONDITIONS**

Aini Noor Liana binti Azmi

Master of Science in Electronic Engineering

2018

**ANALYSIS OF WEARABLE ANTENNA USING ELECTROMAGNETIC BAND GAP
UNDER BENDING CONDITIONS**

AINI NOOR LIANA BINTI AZMI

**A thesis submitted
in fulfillment of the requirements for the degree of Master of Science in
Electronic Engineering**

Faculty of Electronic and Computer Engineering

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2018

DECLARATION

I declare that this thesis entitle “Analysis of Wearable Antenna Using Electromagnetic Band Gap Under Bending Conditions” is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature :

Name : Aini Noor Liana binti Azmi

Date :

APPROVAL

I hereby declare that I have read this thesis and in my opinion this thesis is sufficient in terms of scope and quality for the award of Master of Science in Electronic Engineering

Signature :

Name : Dr. Mohd Sa'ari bin Mohamad Isa

Date :

DEDICATION

To my beloved mother, father, husband, our lovely twins and my family.

ABSTRACT

Wearable antenna caught many attentions among researchers due to its wide applications in the technology. The wearable antenna can be widely applied in military, medical, tracking, and many other fields due to its capability to function on the body and off the body. It is an advantage if the wearable antenna could operate with wide bandwidth. However, there are some drawbacks when designing wideband antenna. Backward radiation is one of the major drawbacks introduced by a wearable antenna. Therefore, it is crucial to reduce the backward radiation to avoid harm to the user. Hence, this thesis presents a wearable antenna integrated with Electromagnetic Band Gap (EBG) structure to perform at particular dual-band Wireless Local Area Network (WLAN) frequencies; 2.4 GHz and 5.2 GHz. EBG structure is a type of metamaterial which cannot be found in nature. This structure has become one of the interests due to its extraordinary response to electromagnetic waves. The wearable antenna is designed in the form of circular ring microstrip patch antenna. Jeans have been used as the medium of the substrate. Jeans fabric is selected due to its high permittivity and inelasticity compared to the other materials. The overall size of the antenna is 70x70mm. In order to improve the performance of the antenna, an EBG is then designed to be integrated with the proposed wearable antenna. Next, the designed structures have been fabricated and measured for return loss, gain, directivity, and radiation pattern. The integration of the wearable antenna with the EBG structure has improved the overall performance. The gain of 5.711 dB and 7.474 dB has been achieved for both high and low resonating frequencies respectively, which shows almost 63.7% improvement at low frequency and 121.4% at high frequency. As the designed antenna is designed to be worn on the body, the bending effect of the structure is studied. Cylindrical foams are used to replace human torso for this purpose. Three radiuses have been selected, representing adult's wrist, arm, and thigh. The overall structure is then been tested under bending conditions; resulting intangible effect to the antenna's performances compared to the flat antenna. The return loss for the antenna was found to be very little affected by the presence of body which makes the designed antenna to be suitable for the wearable communication system. Thus, this antenna is suitable for WLAN application purposed especially for medical, consumer electronics sectors and military field. The details of the measured and simulated are presented and discussed.

ABSTRAK

Antena boleh pakai menarik perhatian dalam kalangan penyelidik atas penggunaannya yang luas dalam teknologi. Antena boleh pakai boleh digunakan secara meluas dalam ketenteraan, perubatan, penjejakan, dan banyak bidang lain kerana keupayaannya berfungsi atas badan dan pada badan. Ia adalah kelebihan jika antena boleh pakai mampu beroperasi dengan jalur lebar. Walau bagaimanapun, terdapat beberapa kekurangan ketika mencipta antena jalur lebar. Sinaran ke belakang adalah salah satu kelemahan utama yang diperkenalkan oleh antena boleh pakai. Oleh itu, adalah penting untuk mengurangkan sinaran ke belakang untuk mengelakkan kemudaratan kepada pengguna. Oleh itu, tesis ini memaparkan satu antena boleh pakai yang disatukan dengan struktur Gerbang Jalur Elektromagnet (EBG) untuk melaksanakan frekuensi rangkaian tanpa wayar kawasan tempatan (WLAN) tertentu; 2.4 GHz dan 5.2 GHz. Struktur EBG adalah sejenis bahan metamaterial yang tidak dapat ditemui secara semulajadi. Struktur ini menjadi salah satu kepentingan kerana tindak balas luar biasa terhadap gelombang elektromagnetik. Antena boleh pakai direka bentuk dalam bentuk tampalan jalur mikro cincin bulat. Kain seluar jeans telah digunakan sebagai medium substrat. Kain seluar jeans dipilih kerana ketelusan yang tinggi dan keupayaannya berbanding dengan bahan lain. Saiz keseluruhan antena ialah 70 x 70 mm. Untuk meningkatkan prestasi antena, EBG kemudian direka untuk disepadukan dengan antena boleh pakai yang dicadangkan. Seterusnya, struktur yang dirancang telah direka dan diukur untuk kehilangan pulangan, keuntungan, corak arah dan corak radiasi. Penyepaduan antena boleh pakai dengan struktur EBG telah meningkatkan prestasi keseluruhan. Keuntungan 5.711 dB dan 7.474 dB masing-masing telah dicapai bagi kedua-dua kekerapan resonansi tinggi dan rendah, yang menunjukkan hampir 63.7% peningkatan pada frekuensi rendah dan 121.4% pada frekuensi tinggi. Oleh kerana antena yang direka adalah untuk dipakai pada badan, kesan lenturan struktur dikaji. Gabus silinder digunakan untuk menggantikan tubuh manusia untuk tujuan ini. Tiga radius telah dipilih, mewakili pergelangan tangan dewasa, lengan dan paha. Struktur keseluruhannya kemudian diuji di bawah keadaan lenturan; menghasilkan kesan tidak ketara kepada prestasi antena berbanding dengan antena datar. Kehilangan pulangan untuk antena itu didapati sangat sedikit terjejas oleh kehadiran badan yang menjadikan antena yang direka sesuai untuk sistem komunikasi yang boleh dipakai. Oleh itu, antena ini sesuai untuk aplikasi WLAN yang bertujuan terutama untuk medan, sektor elektronik pengguna dan bidang ketenteraan. Butiran yang diukur dan disimulasikan disampaikan dan dibincangkan.

ACKNOWLEDGEMENTS

On this opportunity, I would like to state my gratitude to my supervisor, Dr. Mohd Sa'ari bin Mohamad Isa for demonstrating a highly professional character in order to consult and guide me towards the completion of this project.

I would love to express my sincere acknowledgment to lecturers and technicians of Faculty of Electronic and Computer Engineering for their assistance for the analysis works.

Most importantly, I am proud to give my appreciation to my dearest husband, Amirul Fuad bin Abdul Latif for his continuous support and unconditional care which are an indispensable source of my strength. I also love to state my gratitude to my parents, Encik Azmi bin Kamarudin and Puan Rogayah binti Abdul Wahid, for raising me up unconditionally until I was able to achieve this level. Special appreciation to my parents in law, for loving me just like their own daughter, giving all love and care since the first moment we became family. To my siblings and family, I am indebted to them for their support in everything that I have done.

Special thanks to all my colleagues, for their moral support in completing this degree. Lastly, thank you to everyone who had been associated with the crucial parts of completing this project.

TABLE OF CONTENTS

	PAGE
DECLARATION	
APPROVAL	
DEDICATION	
ABSTRACT	i
ABSTRAK	ii
ACKNOWLEDGEMENTS	iii
TABLE OF CONTENTS	iv
LIST OF TABLES	vi
LIST OF FIGURES	vii
LIST OF ABBREVIATIONS	xii
LIST OF PUBLICATIONS	xiv
CHAPTER	
1. INTRODUCTION	1
1.1 Research Background	1
1.2 Problem Statement	3
1.3 Objectives	4
1.4 Work Scopes	5
1.5 Outlines of Thesis	5
2. LITERATURE REVIEW	7
2.1 Introduction to Antenna	7
2.2 Microstrip Patch Antenna	8
2.3 Wearable Antenna	9
2.3.1 Circular Antenna	12
2.4 Introduction to Electromagnetic Band Gap (EBG)	17
2.4.1 Metamaterial	19
2.4.2 EBG Structures	19
2.4.3 EBG Applications	21
2.4.3.1 Surface Wave Oppression with Antenna Substrate	21
2.4.3.2 Efficiency of Small Antenna Design with Antenna Substrate	22
2.4.3.3 Reflection and Transmission Surfaces for High Gains	23
2.4.4 High Impedance Surface (HIS) Structure	24
2.4.5 Mushroom-like Electromagnetic Band Gap (EBG)	25
3. DEVELOPMENT OF WEARABLE ANTENNA	28
3.1 Introduction	28
3.1.1 Flow of Work	31
3.2 Wearable Antenna Structures	32
3.2.1 Design Specifications	32
3.2.2 Antenna Dimensions	34

3.2.3	Wearable Antenna Performances	44
3.2.3.1	Return Loss, Antenna Gain and Efficiency	44
3.2.3.2	Radiation Pattern	47
3.2.3.3	Surface Current	50
3.3	Bending of Wearable Antenna	53
3.3.1	Bending Variations of Wearable Antenna	54
3.3.2	Bending of Wearable Antenna on Three Cases (Radius = 33.5 mm, 47.5 mm, 58.5 mm)	58
3.4	Summary	76
4.	DEVELOPMENT OF ELECTROMAGNETIC BAND GAP (EBG) STRUCTURE	78
4.1	Introduction	78
4.2	Dual Band Electromagnetic Band Gap (EBG)	79
4.2.1	Electromagnetic Band Gap (EBG) Unit Cell	80
4.2.1.1	Unit Cell Design	80
4.2.1.2	Unit Cell Reflection Phase	82
4.2.2	Electromagnetic Band Gap (EBG) Structure	83
4.2.2.1	EBG Dimensions	83
4.2.2.2	EBG Structure Performance	85
4.2.3	Full Structure of Wearable Antenna with Electromagnetic Band Gap (EBG)	85
4.2.3.1	Integration of Wearable Antenna with Electromagnetic Band Gap (EBG) Structure	86
4.2.3.2	Performance of Wearable Antenna vs. Antenna Integrated with EBG	89
4.2.3.2.1	Reflection Coefficient and Gain	90
4.2.3.2.2	Radiation Pattern	93
4.2.3.2.3	Surface Current	97
4.3	Bending of Wearable Antenna Integrated with EBG Structure	103
4.3.1	Bending Technique	103
4.4	Summary	119
5.	CONCLUSION AND FUTURE WORKS	121
5.1	Conclusion	121
5.2	Suggestion for Future Works	123
	REFERENCES	124

LIST OF TABLES

TABLE	TITLE	PAGE
3.1	Design Specifications	33
3.2	Simplified Wearable Antenna Parameters	35
3.3	Return Loss, Realized Gain and Directivity Values of the Antenna with Different Substrate Material	41
3.4	Dimension of Proposed Wearable Antenna	43
3.5	Simulated Gain and Directivity for Wearable Antenna	47
3.6	Summary of Bending Effects on the Wearable Antenna	55
4.1	Antenna integrated with Electromagnetic Band Gap (EBG) Specifications	79
4.2	Dimension of Electromagnetic Band Gap (EBG) Structure	84
4.3	Dimension of Full Structure	88
4.4	Simulated Gain and Directivity for Antenna with EBG	92
4.5	Simulated Performances of Structure on Vertical-plane Bending	109
4.6	Simulated Performances of Structure on Horizontal-plane Bending	110

LIST OF FIGURES

FIGURE	TITLE	PAGE
2.1	Antenna as a transition device (Balanis, 2012)	8
2.2	Steps of designing wearable antennas (Isa et al., 2014)	11
2.3	Conventional Circular Patch Antenna	14
2.4	Dependence of normalized resonant frequency on substrate thickness (Carver, 1981)	14
2.5	Dependence of resonant radiation resistance on substrate thickness for circular microstrip patch (Carver, 1981)	15
2.6	Circular Ring Antenna (Farooq et al., 2015)	16
2.7	Circular Ring Antenna for Size Miniaturization (Mondal, 2017)	17
2.8	Antenna Challenges in Wireless Communication (Ayop et al., 2007)	18
2.9	EBG Structure placed in between antenna array for surface wave oppression (Yang and Samii, 2009)	22
2.10	High Gain Resonator using a Woodpile EBG Structure (Yang and Samii, 2009)	23
2.11	Geometries (a) Top view of Mushroom-like EBG (b) Cross view of Mushroom-like EBG (c) Top view of Uni-planar EBG (d) Cross view of Uni-planar EBG (Yang and Samii, 2009)	25

2.12	Mushroom-like EBG geometry (a) Mushroom-like EBG Surface (b) Equivalent LC circuit (c) LC model (Yang and Samii, 2009; Isa et al., 2014)	26
3.1	Flow chart of research	31
3.2	Impedance Calculation using CST Software	38
3.3	Basic Antenna Design (a) Front view (b) Back view	39
3.4	Parametric study result of variation of ground plane length	40
3.5	Parametric study result of variation of substrate material	40
3.6	Geometry of Circular Monopole Patch Antenna (a) Front view (b) Back view	42
3.7	Parametric Studies on Variation of Inset Length	46
3.8	Reflection Coefficient of Simulated and Measured Antenna	46
3.9	3-D Radiation Pattern of Wearable Antenna (a) 2.4 GHz (b) 5.2 GHz	48
3.10	2-D Radiation Pattern of Simulated and Measured Wearable Antenna (a) 2.4 GHz (b) 5.2 GHz	49
3.11	Surface Current for Wearable Antenna at 2.4 GHz (a) 0° (b) 45° (c) 90° (d) 135° (e) 180°	51
3.12	Surface Current for Wearable Antenna at 5.2 GHz (a) 0° (b) 45° (c) 90° (d) 135° (e) 180°	53
3.13	Simulation Arrangement of Antenna Bending (a) Vertical-plane bending (b) Horizontal-plane bending	55
3.14	Simulated Reflection Coefficient of (a) Vertical-plane bending (b) Horizontal-plane bending	56

3.15	Measurement Arrangement of Antenna Bending (a) Vertical-plane bending (b) Horizontal-plane bending	60
3.16	Simulated Reflection Coefficient of Antenna on Vertical-plane Bending	60
3.17	Simulated and Measured Reflection Coefficient of Antenna on Vertical-plane Bending (a) Case 1 (b) Case 2 (c) Case 3	62
3.18	Simulated Reflection Coefficient of Antenna on Horizontal-plane Bending	62
3.19	Simulated and Measured Reflection Coefficient of Antenna on Horizontal-plane Bending (a) Case 1 (b) Case 2 (c) Case 3	64
3.20	Azimuth radiation pattern of Vertical-plane at 2.4 GHz (a) Case 1 (b) Case 2 (c) Case 3	65
3.21	Azimuth radiation pattern of Vertical-plane at 5.2 GHz (a) Case 1 (b) Case 2 (c) Case 3	67
3.22	Azimuth radiation pattern of Horizontal-plane at 2.4 GHz (a) Case 1 (b) Case 2 (c) Case 3	68
3.23	Azimuth radiation pattern of Horizontal-plane at 5.2 GHz (a) Case 1 (b) Case 2 (c) Case 3	70
3.24	Elevation radiation pattern of Vertical-plane at 2.4 GHz (a) Case 1 (b) Case 2 (c) Case 3	71
3.25	Elevation radiation pattern of Vertical-plane at 5.2 GHz (a) Case 1 (b) Case 2 (c) Case 3	73
3.26	Elevation radiation pattern of Horizontal-plane at 2.4 GHz (a) Case 1 (b) Case 2 (c) Case 3	74

3.27	Elevation radiation pattern of Horizontal-plane at 5.2 GHz (a) Case 1 (b) Case 2 (c) Case 3	76
4.1	Unit cell geometry. Optimized dimension: $p=49$ mm, $r_{e1}=23.6$ mm, $r_{e2}=15.8$ mm, $r_{via}=0.6$, $g=1$	81
4.2	Reflection phase of a unit cell EBG structure	82
4.3	Electromagnetic Band Gap (EBG) Structure (a) Front view (b) Back view	83
4.4	Placement of Strip Line on EBG Structure	84
4.5	Transmission Coefficient of EBG structure	85
4.6	Dual Band Conventional Antenna integrated with EBG Structure (a) Front view (b) Back view (c) Side view	87
4.7	Fabricated Dual Band Wearable Textile Antenna Integrated with EBG	89
4.8	Reflection Coefficient of Simulated and Measured Conventional Antenna on EBG Structure	91
4.9	Reflection Coefficient of Simulated and Measured Conventional Antenna and Antenna with EBG	92
4.10	3-D Radiation Pattern of Conventional Antenna with EBG (a) 2.4 GHz (b) 5.2 GHz	94
4.11	Comparison of Simulated and Measured Radiation Pattern of Antenna with and without EBG (a) Vertical-plane at 2.4 GHz (b) Vertical-plane at 5.2 GHz (c) Horizontal-plane at 2.4 GHz (d) Horizontal-plane at 5.2 GHz	96
4.12	Surface Current for Antenna with EBG at 2.4 GHz (a) 0° (b) 45° (c) 90° (d) 135° (e) 180°	100

4.13	Surface Current for Antenna with EBG at 5.2 GHz (a) 0° (b) 45° (c) 90° (d) 135° (e) 180°	102
4.14	Simulated bending of antenna with EBG (a) Vertical-plane bending (b) Horizontal-plane bending	103
4.15	Simulated Reflection Coefficient of Structure on Vertical-plane Bending	105
4.16	Simulated and Measured Reflection Coefficient of Structure on Vertical-plane Bending	107
4.17	Simulated Reflection Coefficient of Structure on Horizontal-plane Bending	107
4.18	Simulated and Measured Reflection Coefficient of Structure on Horizontal-plane Bending	109
4.19	Simulated and measured radiation pattern of structure when bended under all cases	118

LIST OF ABBREVIATIONS

WLAN	-	Wireless Local Area Network
ISM	-	Industrial, Scientific and Medical
MPA	-	Microstrip Patch Antenna
RF	-	Radio Frequency
RL	-	Return Loss
BW	-	Bandwidth
Γ	-	Reflection Coefficient
P	-	Power
Z	-	Impedance
f	-	Frequency
E	-	Electrical Field
M	-	Magnetic Field
EBG	-	Electromagnetic Band Gap
CST	-	Computer Simulation Technology
IEEE	-	Institute of Electrical and Electronic Engineers
HIS	-	High Impedance Surface
SAR	-	Specific Absorption Rate
HPBW	-	Half Power Beamwidth
FNBW	-	First Null Beamwidth
DUT	-	Device Under Test
GHz	-	Giga Hertz

dB - Decibel
mm - Milimeter
MHz - Mega Hertz

LIST OF PUBLICATIONS

The research papers produced and published during the course of this research are as follows:

1. M.S.M. Isa, A.N.L. Azmi, A.A.M. Isa, M.S.I.M. Zin, M. Abu, Z. Zakaria, M.S.M. Saat, and A. Ahmad, 2014. Analysis on the Performance of Textile Circular Antenna under Bending Conditions, *Malaysian Technical Universities Conference Engineering & Technology (MUCET)*, Melaka, Malaysia, November 10-11.
2. M.S.M. Isa, A.N.L. Azmi, A.A.M. Isa, M.S.I.M. Zin, M. Abu, Z. Zakaria, M.S.M. Saat, and A. Ahmad, 2015. Comparative Study of Mutual Coupling on Microstrip Antennas for Wireless Local Area Network (WLAN) Application, *Journal of Telecommunication, Electronic and Computer Engineering (JTEC)*,
3. M.S.M. Isa, A.N.L. Azmi, A.A.M. Isa, M.S.I.M. Zin, M. Abu, Z. Zakaria, M.S.M. Saat, and A. Ahmad, 2014. Wearable Textile Antenna on EBG for WLAN Applications, *Journal of Telecommunication, Electronic and Computer Engineering (JTEC)*, Vol. 6, July 2014, pp 51-58.

CHAPTER 1

INTRODUCTION

This chapter presents an overview on the research background of the project and covers the problem statement, objectives, and work scopes of the research. This chapter also describes briefly the flow of the thesis.

1.1 Research Background

The technology of mobile communication has grown remarkably. The history of this communication starts with the operation of first generation (1G), followed by the second generation (2G), where the system is mainly voice application with digital technology. The technology then expanded to third generation (3G) which offers better technology with better data rate. Over the year, the latest technology is the fourth generation (4G). In recent years, body centric wireless communication becomes one of the important parts in the 4G mobile communication system.

Body centric communication takes place in between two networks, personal area networks (PANs) and body area networks (BANs). There are two concepts involved in this communication which are on-body communication and off-body communication (Wei et al., 2017). The on-body communication defines communication between wireless implants and body nodes while off-body communication takes place when the body worn device communicates with any mobile or base units located around the environment.

In the past several decades, major enhancements of off-body antenna designs have been identified. In supporting the increasing in antennas and propagation of the off-body centric communication system, numerous technologies have been introduced in the modern antenna design field (Agarwal et al., 2016; Paraskevopoulos et al., 2017). One of the dominant research topics in antennas for body centric communications is wearable, and fabric based antennas which are popularly called as textile antennas.

Much interest is currently focusing in body-worn communication systems especially for motion detection on the body. Other than that, there are numbers of applications of this technology which include paramedics, military and fire fighters. Hence, body worn antennas made by textile have been introduced which can be applied into clothing with ideal performance at low cost.

However, some drawbacks have been identified when applying the antenna on body such as the low power gain and the presence of backward radiation. Due to that, metamaterial studies are reported to find the solution to the challenges. Metamaterial technology is one of the most popular technology and becoming an interest in electromagnetic properties study. Metamaterials are attractive as they have the desired electromagnetic properties which cannot be found in natural materials. One of the metamaterial subset is electromagnetic band gap (EBG) structure. It has been reported by (Basit & Karu 2012) that a large variety of electromagnetic band gap (EBG) structures have been introduced in order to achieve directive radiation.

The discovery of these EBG structures has the promising solutions to solve the body worn antenna drawbacks. The production of EBG also able to suppress surface waves in the antenna ground plane besides reducing the backward radiation of antenna and improving the antenna gain. In addition, this structure will respond to another drawback which is the surface waves in the antenna ground plane by suppressing the amount of

waves during propagation. Due to that, the deployment of EBG structure integrated with wearable antenna will prove the superiority of these structures by improving the antenna performances through this project.

1.2 Problem Statement

In modern antenna design, there is great attention in wearable antennas in both the civil and military domains. In the civil domain there is a move towards pervasive computing which utilizes various electronic devices placed around the body and new development in Green technology with the development towards RF energy harvesting. Flexible, conformal antennas are essential to provide an unobtrusive solution as continues RF energy can be generated when the module can be wearable (Langley and Shaozhen, 2009). Consequently, authors have introduced many antennas especially on network communication at 2.45 GHz and 5-6 GHz for on body applications. The development and assessment of the flexible wearable antennas which are integrated into clothing have become one of the interests to be analysed for these applications.

Furthermore, people tend to use more than one communication system at the same time. These are important as the capabilities of multiband with wide bandwidth are popular for most microwave region applications, such as Radio Frequency Identification (RFID), Wireless Local Area Network (WLAN), and Global Positioning System (GPS). Therefore, it is crucial to develop on body communication system, coinciding with the recent demand on high efficiency and high mobility technologies.

The problem has arisen with the bending effect to the antenna performances, as human will make movement in every single moment. The advantage of studying the bending effect is that the wearable antenna would be able to conform to the surface of the body; therefore they must be able to withstand a certain amount of structural deformation.

The method of bending is by placing the antenna on curved surface, such as foam with air permittivity to represent open surface. In this project, focus is given on the return loss, gain, efficiency, as well as the radiation pattern of the structure due to effect of providing additional resistance to the physical structure.

The other issue on the design of the antenna is the conformability for wearing on body in terms of health. In order to achieve wide bandwidth, the backward radiation of the antenna will be increased. The concern is to reduce the radiation as much as possible so that more power transmit is developed, and less power is absorbed by the body. Meanwhile, the are limitations of the proposed wearable antenna, as it should be designed by using inelastic fabric material with low permittivity, as well as low profile structure.

1.3 Objectives

The objectives of the research are as follows:

1. To design a wideband wearable antenna operating in WLAN frequency range; 2.4 GHz and 5.2 GHz.
2. To investigate and analyse the bending effect of the antenna on the antenna's performances.
3. To reduce the backward radiation of the wearable antenna using Electromagnetic Band Gap (EBG).