



**Preparation and Characterization of Polyaniline Graphene
Nanoplatelets Conductive Nanocomposite for Wearable
Textile Antenna**

اونيور سيتي تیکنیکل ملیسیا ملاک
UNIVERSITI TEKNIKAL MALAYSIA MELAKA

NOR AISAH BINTI KHALID

DOCTOR OF PHILOSOPHY

2024



**Faculty of Industrial and Manufacturing Technology and
Engineering**



**Preparation and Characterization of Polyaniline Graphene Nanoplatelets
Conductive Nanocomposite for Wearable Textile Antenna**

Nor Aisah binti Khalid

Doctor of Philosophy

2024

Preparation and Characterization of Polyaniline Graphene Nanoplatelets Conductive Nanocomposite for Wearable Textile Antenna

NOR AISAH BINTI KHALID



Faculty of Industrial and Manufacturing Technology and Engineering

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2024

DEDICATION

This is in memory of the sake of Allah, my Creator and messenger, Mohammed (May Allah bless and grant him), who taught us the purpose of life. I dedicate my dissertation work to my family and beloved people who have meant so much to me. A special feeling of gratitude goes to my loving parents, Keling @ Khalid Bin Che Man and Patimah Binti Seman whose words of encouragement and push for tenacity ring in my ears. Although my mother is no longer in this world, their memories continue to regulate my life. Thank you so much “Mak”, I will never forget you. Thank you to my sisters Norayah and Kamariah who have never left my side and are very special. Also for my brothers Hamdan, Aziz, Hamran, Amir, Hadi, Zulhelmi and Firdaus. I am truly thankful for having you in my life. I am grateful to my friends. I will always appreciate all they have done especially for helping me develop my research skills and for being a constant source of support and encouragement during the challenges of graduate school and life. I love you all and miss you all beyond words. May Allah (SWT) grant you Jannah Firdaus. Amen.

ABSTRACT

Wearable textiles for antennas have growth significantly due to their widespread utilization in comprehensive monitoring, communication and storage systems. Traditional antennas are often bulky and susceptible to corrosion, but the integrating antenna into textiles offers a promising solution for wearable applications. This study explores the use of polyaniline (PANI) combined with graphene nanoplatelets (GNPs) at various loading (0.25 wt%, 0.50 wt%, 0.75 wt% and 1.00 wt%) to create a conductive polymer via oxidative polymerization, aimed at enhancing wireless communication function in electronics devices. Ammonium persulfate (APS) was used as an oxidizing agent in hydrochloric acid (HCl) and aniline monomers were polymerized into elongated PANI chains. Non covalent surface modification technique including π - π stacking, van der Waals forces and electrostatic interactions preserved the GNPs lattice and enhanced the electrical conductivity by charge carrier mobility, resulting in superior antenna characteristics. Screen printing techniques were employed to integrate these materials into wearable structures without compromising antenna performance. A rectangular microstrip patch antenna design, simulated with CST Microwave Studio was printed using a PANI/GNPs mixture mixed with ethylene glycol (EG) and polyvinyl pyrrolidones (PVP) for optimal ink adhesion. Morphological analysis (SEM, FESEM and TEM) showed well-distributed and connected nanoparticles facilitating continuous electron pathways. FTIR, RAMAN and XRD characterizations confirmed the presence of carboxylic acid (COOH) and amine (NH₂) groups, improved structural order and decreased crystallite size indicating enhanced charge carrier connectivity. The 0.75 wt% PANI/GNPs (treated)-DBSA sample exhibited the highest conductivity value at 22.34 S/cm. Simulation and experimental results demonstrated return loss (S_{11}) values of -23.38 dB and -20.78 dB respectively with antenna gain of 2.86 dB at 2.45 GHz and 7.01 at 2.60 GHz. The radiation pattern illustrated a dipole shape for both the E- field and H-field. The successful synthesis of PANI/GNPs with DBSA significantly enhanced electrical conductivity, leading to an optimal conductive ink formulation for microstrip patch antenna fabrication. Experimental validation confirmed improved antenna performance, which is particularly promising for flexible and lightweight WBAN application. In conclusion, PANI/GNPs-DBSA nanocomposites offer a compelling alternative to rigid, expensive materials like copper or FR4 in antenna-based telecommunication applications, paving the way for advanced wearable technology.

PENYEDIAAN DAN PENCIRIAN BAGI POLIANILIN KEPINGAN NANO GRAFIN NANOKOMPOSIT KONDUKTIF BAGI ANTENA TEKSTIL BOLEH PAKAI

ABSTRAK

Antena yang disepadukan pada tekstil boleh pakai telah menyaksikan perkembangan yang pesat disebabkan penggunaannya yang meluas dalam sistem pemantauan, komunikasi dan penyimpanan yang komprehensif. Antena tradisional selalunya besar dan terdedah kepada kakisan, tetapi antena yang disepadukan pada tekstil menawarkan penyelesaian yang berpotensi untuk kepelbagaian penggunaan. Kajian ini meneroka penggunaan polianilin (PANI) digabungkan dengan nano kepingan grafin (GNPs) dengan pelbagai pembebanan 0.25 wt%, 0.50 wt%, 0.75 wt% dan 1.00 wt% untuk mencipta polimer konduktif, melalui pemolimeran pengoksidaan untuk meningkatkan fungsi komunikasi tanpa wayar dalam peranti elektronik. Ammonium persulfate (APS) sebagai agen pengoksidaan dalam asid hidroklorik (HCl), dan monomer anilin bagi menghasilkan rantaian PANI yang tumbuh memanjang. Teknik pengubahsuaian permukaan melalui kaedah bukan kovalen termasuk susunan π - π , daya van der Waals dan interaksi elektrostatik mengekalkan kekisi GNP dan meningkatkan kekonduksian elektrik melalui mobiliti pembawa cas menghasilkan ciri antena yang unggul. Teknik percetakan skrin digunakan bagi menyepadukan bahan ini ke dalam struktur boleh pakai tanpa menjejaskan prestasi antena. Reka bentuk antena segi empat tepat bagi tampalan jalur mikro yang disimulasikan oleh CST Microwave Studio telah di cetak menggunakan campuran PANI/GNPs di campur dengan etilena glikol (EG) dan polivinil pirolidon (PVP) untuk perlekatan dakwat yang optimum. Analisis morfologi (SEM, FESEM dan TEM) menunjukkan nanozarahahan yang teragih secara seragam dan saling berhubung yang memudahkan laluan berterusan bagi aliran elektron. Perincian FTIR, RAMAN dan XRD mengesahkan kehadiran kumpulan asid karboksilik (COOH) dan amina (NH₂), susunan struktur yang lebih baik dan saiz kristal yang berkurangan menunjukkan sambungan pembawa cas yang dipertingkatkan. Sampel 0.75% PANI/GNPs (terawat)-DBSA mempamerkan nilai kekonduksian tertinggi pada 22.34 S/cm. Keputusan simulasi dan ujikaji menunjukkan nilai balikan pulang (S₁₁) masing-masing adalah -23.38 dB dan -20.78 dB dengan janaan antena sebanyak 2.86 dB bagi 2.45 GHz dan 7.01 bagi 2.60 GHz. Corak radiasi menggambarkan reka bentuk dwi-kutub bagi kedua-dua medan E dan medan H. Kejayaan sintesis PANI/GNPs dengan DBSA telah meningkatkan kekonduksian elektrik dengan ketara, membawa kepada formulasi dakwat konduktif yang optimum untuk pembuatan antena tampalan jalur mikro. Ujikaji yang dijalankan telah mengesahkan prestasi antena yang lebih baik, dan amat berpotensi untuk aplikasi WBAN yang fleksibel dan ringan. Kesimpulannya, PANI/GNPs-DBSA menawarkan alternatif yang menarik kepada bahan tegar dan mahal seperti tembaga atau FR4 dalam aplikasi telekomunikasi berasaskan antena, membuka jalan untuk teknologi boleh-pakai termaju.

ACKNOWLEDGEMENTS

In the Name of Allah, the Most Gracious, the Most Merciful

I want to express my deepest gratitude to Allah for granting me the strength and courage to persevere on this journey. My heartfelt thanks go out to everyone who has supported me throughout the years, helping me reach this milestone. First and foremost, I am profoundly grateful to the three individuals who made this project possible. To my supervisor, Associate Professor Ir. Ts. Dr. Jeefferie Bin Abd Razak: your guidance has been a beacon of light, and your unwavering support during my toughest days has given me the resilience to keep going. Your patience and kindness have not only shaped my academic journey but have also enriched my life.

To my co-supervisor, Ir. Dr. Mohd Muzafar Bin Ismail: thank you for your infectious positivity and your invaluable insights that have enhanced my research. Your encouragement has inspired me to strive for excellence. I would also like to extend my gratitude to Mr. Hazman Bin Hasib for providing me with a rich learning experience while working under the project grant. Your teachings have left a lasting impression on my academic growth. I acknowledge the short-term research grant from Universiti Teknikal Malaysia Melaka (UTeM), specifically the Grant No PJP/2019/FKP(4B)/S01662, for the essential financial support that enabled me to carry out this fundamental and exploratory research.

My sincere appreciation goes to the Centre of Smart System and Innovative Design (COSSID) and the Faculty of Industrial and Manufacturing Technology and Engineering (FTKIP) for creating a nurturing environment for my research study. I am also grateful to the dedicated team at the composite and materials engineering laboratory (FTKIP), as well as the antenna and telecommunication laboratory (FTKEK) for their meticulous assistance with measurements and testing, which were vital for the successful completion of my studies.

I would like to express my heartfelt thanks to the thesis examination panel, AP. Ts. Dr. Rose Farahiyah Binti Munawar (UTeM) and AP. Ir. Ts. Dr. Rizwan Bin Ishak (UPM), for their invaluable guidance in improving my thesis.

Lastly, I want to express my heartfelt appreciation to all my postgraduate friends especially Ezyanie, Nida, Kak Najmi and many others. Your emotional support, kindness, and the countless cherished memories we created together have made this journey truly special. You have been my pillars of strength, and I will always treasure our shared experiences. Thank you all for being an integral part of this remarkable journey. Thanks to dear self Aisah. ALHAMDULLILLAH

TABLE OF CONTENTS

	PAGE
DECLARATION	
APPROVAL	
DEDICATION	
ABSTRACT	i
ABSTRAK	ii
ACKNOWLEDGEMENTS	iii
TABLE OF CONTENTS	iv
LIST OF TABLES	viii
LIST OF FIGURES	x
LIST OF SYMBOLS AND ABBREVIATIONS	xx
LIST OF APPENDICES	xxii
LIST OF PUBLICATIONS	1
CHAPTER 1 INTRODUCTION	3
1.1 Background	3
1.2 Problem Statement	7
1.3 Research Objective	11
1.4 Scope of Research	12
1.5 Contribution of the study	14
1.6 Thesis Organization	15
CHAPTER 2 LITERATURE REVIEW	17
2.1 Introduction	17
2.2 Wearable textile antenna	18
2.2.1 Wearable textile antenna technology and its current development	18
2.2.2 Microstrip patch antenna	21
2.2.3 Substrate for wearable textile antenna	24
2.2.4 Antenna designation and fabrication	26
2.3 Wearable textile antenna based conductive material	31
2.3.1 Polymer nanocomposite for the electrical purposes	31
2.3.2 Polyaniline (PANI) as conductive polymer	32
2.3.3 Graphene nanoplatelets (GNPs) and Silver (Ag) as a nanofiller	34
2.3.4 Surface modification on GNPs via non-covalent treatment approach	39
2.3.5 Dedocylbenzene sulfonic acid (DBSA) as a dopant agent	43

2.4	Theory and related fundamental of conductive polymer nanocomposite	46
2.5	Antenna Simulation by CST	47
2.6	Fundamental parameter of wearable antenna	53
2.6.1	Return loss	53
2.6.2	Antenna Gain	55
2.6.3	Radiation pattern	58
2.7	Limitation of the Proposed Methodology	61
2.8	Summary and the study gap	62
CHAPTER 3 METHODOLOGY		66
3.1	Introduction	66
3.2	Proposed Methodology	67
3.3	Experimental setup	69
3.3.1	Phase 1 : Synthesis of PANI/GNPs-DBSA by Oxidation Polymerization of Aniline for untreated GNPs.	69
3.3.2	Phase 2 : Surface treatment of GNPs nanofiller by non covalent method for maximum conductive ink formulation for microstrip patch.	71
3.3.3	Phase 3 : a) Screen printing process for microstrip patch antenna	73
3.3.4	Phase 3 :b) To compare wearable antenna performance of PANI/GNPs between the experimental and simulation method	74
3.4	Material specification	75
3.5	Synthesis of Conductive Patch	77
3.5.1	Oxidation Polymerization of PANI/GNPs(untreated)-DBSA	77
3.5.2	Surface Modification - Non Covalent PANI/GNPs(treated)-DBSA	81
3.6	Characterization and testing of PANI nanocomposite	83
3.6.1	Morphological Testing	83
3.6.2	Physical and Chemical Testing	85
3.6.3	Electrical Conductivity Testing	87
3.7	Simulation of antenna by Computer Simulation Technology (CST)	89
3.7.1	Computer Simulation Technology (CST) designation	89
3.7.2	Substrate	90
3.7.3	Patch	91
3.7.4	Ground	92
3.7.5	Feedline	93
3.7.6	Port	94
3.7.7	Analysis return loss, antenna gain and radiation pattern by CST	95
3.8	Experimental of Microstrip Patch Antenna by screen printing technique	95
3.9	Fabrication of Microstrip Patch Antenna	96
3.9.1	Antenna with ground – Screen printing process	96
3.10	Performance Testing for Wearable Antenna	98
3.10.1	Return Loss	99
3.10.2	Antenna Gain	100
3.10.3	Radiation pattern	101
3.11	Summary	102
CHAPTER 4 RESULTS AND DISCUSSION		104
4.1	Introduction	104

4.2	Phase 1: Objective 1 - To synthesis PANI by oxidation polymerization of aniline through the effect of various GNPs nanofiller loading and reaction with DBSA acid dopant for optimum electrical conductivity.	105
4.2.1	Morphological characteristics of PANI/GNPs (untreated)	105
4.2.2	Physical & Chemical testing of PANI/GNPs(untreated) nanocomposites	119
4.2.3	Electrical conductivity testing of PANI/GNPs(untreated) nanocomposites	128
4.3	Phase 2: To evaluate the effect of non-covalent surface treatment and Ag nanoparticle hybridization in the conductive ink formulation for optimum electrical conductivity.	131
4.3.1	Scanning electron microscopy (SEM) analysis for PANI/GNPs (treated)-DBSA with Ag nanoparticles nanocomposites	132
4.3.2	Field emission scanning electron microscope (FESEM) analysis for PANI/GNPs (treated)-DBSA with Ag nanoparticles nanocomposites	137
4.3.3	Transmission electron microscope (TEM) analysis for PANI/GNPs(treated)-DBSA with Ag nanoparticles nanocomposites	142
4.3.4	Fourier Transform Infrared (FTIR) analysis for PANI/GNPs (treated)-DBSA with Ag nanoparticles Nanocomposites	148
4.3.5	Raman spectroscopy (RAMAN) analysis for PANI/GNPs (treated)-DBSA with Ag nanoparticles nanocomposites	154
4.3.6	X-ray diffraction (XRD) analysis for PANI/GNPs (treated)-DBSA with Ag nanoparticles nanocomposites	159
4.3.7	Electrical conductivity-four point probe analysis for PANI/GNPs (treated)-DBSA with Ag nanoparticles nanocomposites	163
4.4	Phase 3: To establish the relationship between the morphological, physical and electrical properties of PANI/GNPs-DBSA nanocomposites by characterization testing against performance of wearable antenna application.	168
4.4.1	Simulation antenna by CST microwave studio	168
4.4.2	CST simulation results for antenna return loss and bandwidth	171
4.4.3	Experimental measurement result for Return loss and bandwidth of the prototype antenna	173
4.4.4	Antenna gain and VSWR by the CST simulation	176
4.4.5	Antenna gain and VSWR experimental results for the antenna prototype	177
4.4.6	Radiation pattern of antenna by CST simulation	179
4.4.7	Radiation pattern for the prototype antenna	182
4.4.8	The comparison result of return loss, antenna gain, radiation pattern with the previous study	185
4.5	Summary	189
CHAPTER 5 CONCLUSION AND RECOMMENDATIONS		191
5.1	Conclusions	191
5.2	Recommendations	194
REFERENCES		196
APPENDICES		232

Antenna Design and methodology	232
The structure of antenna which is Gucci-shaped	232
1.0 Designing antenna	233
Design and simulation in CST Studio software	234
1.1 Creating Project Template	234
1.2 Forming a Ground Patch	238
1.3 Forming a Substrare	238
1.4 Forming Patch Plane	239



LIST OF TABLES

TABLE	TITLE	PAGE
Table 2.1	The dielectric constant (ϵ_r) for various normal textile fabrics	26
Table 2.2	Various PANI filled composites with the electrical conductivity values.	37
Table 2.3	Influence of DBSA dopant addition to the value of electrical conductivity of PANI polymer	44
Table 2.4	Antenna parameter explanation of bandwidth and return loss results for the performance at different resonant frequencies	55
Table 2.5	The parameter of antenna gain and VSWR results in performance at different resonant frequencies	58
Table 2.6	Antenna parameter explanation of radiation pattern results in performance at different resonant frequencies	60
Table 3.1	The materials description of experimental setup for wearable textile antenna based PANI/GNPs-DBSA	76
Table 3.2	PANI synthesis with various untreated-treated GNPs loading and PANI with and without the presence of Ag hybrid	80
Table 4.1	Raman parameter for PANI/GNPs(untreated)-DBSA with various loading of GNPs untreated.	125
Table 4.2	Raman parameter for PANI/GNPs (treated)-DBSA with various loading of GNPs treated	156
Table 4.3	Raman parameter for PANI/GNPs (treated)/Ag DBSA with 0.75wt% loading of Ag	158

Table 4.4	Wearable antenna design specification parameters	170
Table 4.5	The comparison between simulation and measurement of wearable textile antenna return loss.	175
Table 4.6	The comparison between simulation and measurement of	179
Table 4.7	The comparison between simulation and measurement of radiation pattern.	185
Table 4.8	The comparison of wearable textile antenna parameter between return loss, antenna gain, and radiation pattern. critical discussion.	188



LIST OF FIGURES

FIGURE	TITLE	PAGE
Figure 2.1	Wearable textile antenna stitch onto non-conductive textile (Tsolis et. al., 2014)	20
Figure 2.2	Structure of microstrip patch antenna with feed line (Dheyaa Khaleel, 2012)	23
Figure 2.3	The process of screen printing (A-conductive ink, B-squeegee, C-polyester screen mesh, D- hardwood screen frame, E-design pattern, and F-textile) (Huating et al., 2019)	28
Figure 2.4	Oxidation states of PANI, (A) the completely reduced Leucoemeraldine base, (B) the fully oxidized pernigraniline base, (C) the half oxidized-half reduced emeraldine base; and (D) the emeraldine salt, (Qazi et al., 2014).	34
Figure 2.5	Schematic representation of PANI with GO and CNT nanofiller dispersion for better filler-matrix interaction (Sagar et al., 2023).	35
Figure 2.6	Difference nanofiller of multi-walled carbon nanotubes (MWCNTs) and graphene nanoplatelets (GNPs) for electrical conductivity response (Chatterjee et al., 2011).	36
Figure 2.7	Schematic illustration for synthesis of metal nanoparticle embedded reduced graphene oxide (rGO-AgNP) by reduction duality of formic acid (Yoon et al., 2015).	39
Figure 2.8	Simulated and measured radiation patterns of the antenna in free space when relaxed at: (a) 2.45 GHz, (b) 5.25 GHz and (c) 5.75 GHz (Azeez et al., 2019).	59

Figure 3.1 Methodology framework of PANI/GNPs-DBSA testing for wearable textile antenna.	68
Figure 3.2 The synthesis process of PANI/GNPs-DBSA by oxidation polymerization of aniline.	70
Figure 3.3 The surface treatment of GNPs nanofiller by non covalent method.	72
Figure 3.4 The fabrication process of microstrip patch antennas by using the screen printing method.	73
Figure 3.5 The Morphological, physical and electrical properties of PANI/GNPs-DBSA against wearable antenna characteristics.	75
Figure 3.6 (a) The 15.54g of Anilinium Chloride (AN) mixed with 300 ml of Distilled water (DI), (b) Ammonium Persulphate (APS) mixed with 300ml of Distilled water (DI), (c) Dedocylbenzene sulfonic acid (DBSA) and (d) Pure GNPs in powder foam.	78
Figure 3.7 (a) AN and APS were mixed together in a beaker, (b) The solution washed with HCL and acetone during the filtration process.	79
Figure 3.8 a) Solid-liquid PANI/GNPs-DBSA was collected, (b) The PANI/GNPs-DBSA after dried in a vacuum oven, (c) Dry specimen was grind to obtain pristine PANI/GNPs nanocomposite powder.	79
Figure 3.9 (a) 16.6 ml Hydrochloric acid (HCl) was taken using a burette, (b) 250 ml DI were taken, (c) 733.4ml distilled water is then add into 1000ml volumetric flask.	81
Figure 3.10 (a) About 5 g of pure GNPs nanofiller are prepared for surface treatment process, (b) solution was sonicated by ultrasonic bath, (c) Suspension	

- was mixed under vigorous stirring and (d) The obtained black precipitate was washed for three times with distilled water. 82
- Figure 3.11 (a) Non-covalent treated GNPs was dried at 150°C, (b) Product was grinding to obtain PANI/GNPs-PEI treated powder. 82
- Figure 3.12 The SEM was measured at 15 kV using a ZEISS machine, (b) The TEM was recorded by Talos L 120 from Thermofisher, (c) The FESEM test with EDX was carried out by JSM-7600F from JEOL. 85
- Figure 3.13 The prepared PANI/GNPs- DBSA nanocomposite was examined by (a) Fourier transform infrared (FTIR) testing machine by JASCO model FT/IR-6000 spectrometer, (b) Raman spectrometer (UniRAM-3500), (c) XRD measurement by X'PERT PRO MPD PW3060/60 x-ray diffractometer analyzer. 87
- Figure 3.14 (a) About 0.3 g of PANI/GNPs was insert into the mold; (b) Press by applying 5 tonne of compression force. 88
- Figure 3.15 (a) The pellet sizes of 9 mm (diameter) and 2.8mm (thickness), which are produced and then removed; (b) the pellet was measured by using a vernier caliper; (c) Equipment for surface resistance and electrical conductivity measurements. 88
- Figure 3.16 Selection on MW & RF & OPTICAL and planar for microstrip patch antenna by using the CST simulation and modelling method. 90
- Figure 3.17 Substrate length and width that has been estimated for wearable textile antenna simulation. 91
- Figure 3.18 The patch size was in accordance to the 2.45 GHz safety guidelines for the tissue body). 92

Figure 3.19 In wearable antenna, ground is located on the front and narrow gap of CPW that is required for better antenna design.	93
Figure 3.20 Designation critical on the feed-line including a width (FW), length (FL) and height (FH).	94
Figure 3.21 SMA connector was installed on the port to get antenna performance analysis by using soldering approach.	94
Figure 3.22 (a) The accublack design of antenna b) Photo emulsion for screen Printing c) Hardwood screen printing mesh d) Screen was layered with accublack design e) Expose to the uv lighting for 10 minute f) The screen was rinse by water to remove unexposed emulsion.	97
Figure 3.23 a) 0.5g PVP in powder form b) 10ml of ethlyne glycol (EG) c) 5g PANI/GNPs, PVP and EG were mixed d) PANI/GNPs-DBSA ink was pour on the top of the screen mesh e) Printed PANI/GNPs-DBSA were pressed on a hotplate.	98
Figure 3.24 The Vector Network Analysis (VNA) of the antennas applied with the return loss.	99
Figure 3.25 Antenna gain estimated via spectrum analyzer (SA).	100
Figure 3.26 Measurement analysis of radiation pattern by anechoic chamber.	102
Figure 4.1 SEM image of pure GNPs nanofiller under 100x of magnification.	106
Figure 4.2 SEM image of PANI-DBSA polymer without GNPs nanofiller under 100x of magnification.	107
Figure 4.3 SEM image of PANI/GNPs (untreated)-DBSA nanocomposites with 0.25 wt% of GNPs nanofiller loading at 300x of magnification.	108

Figure 4.4 SEM image of PANI/GNPs (untreated)-DBSA nanocomposite with 0.50 wt% of GNPs nanofiller loading at 300x of magnification.	108
Figure 4.5 SEM image of PANI/GNPs (untreated)-DBSA nanocomposites with 0.75wt% of GNPs nanofiller loading at 300x of magnification.	109
Figure 4.6 SEM image of PANI/GNPs (untreated) -DBSA nanocomposites with 1.00wt% of GNPs nanofiller loading at 300x of magnification.	110
Figure 4.7 a) The pure GNP at 20k of magnification (b) and (c) FESEM-EDX analysis of pure GNPs nanofiller powder.	111
Figure 4.8 a) The pure PANI at 100k of magnification; (b) and (c) FESEM-EDX analysis of pure PANI polymer.	112
Figure 4.9 Fesem image of PANI/GNPs (1.00wt% untreated) observed at the 20kx of magnification without DBSA dopant.	113
Figure 4.10 Fesem image of PANI-DBSA observed at the 20kx of magnification.	113
Figure 4.11 FESEM image of PANI/GNPs (untreated)-DBSA nanocomposites at 20kx of magnification with 0.25 wt% loading of GNPs nanofiller without surface treatment.	115
Figure 4.12 FESEM image of the PANI/GNPs (untreated)-DBSA at 20kx magnification with 0.75 wt% loading of GNPs nanofiller without surface treatment.	115
Figure 4.13 FESEM image of the PANI/GNPs (untreated)-DBSA at 20kx of magnification with 1.00 wt% loading of GNPs nanofiller without surface treatment.	116
Figure 4.14 PANI-DBSA without GNPs addition at 120kx of magnification.	117

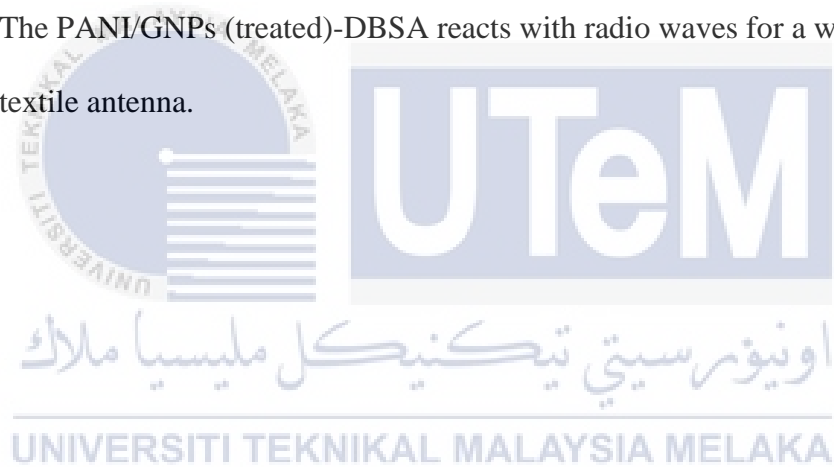
Figure 4.15 PANI/GNPs (Untreated)-DBSA with 0.75wt% GNPs nanofiller loading at 120 kx of magnification.	118
Figure 4.16 PANI-DBSA without GNPs nanofiller loading at 57kx of magnification.	119
Figure 4.17 PANI/GNPs (1.0wt%) at 57kx of magnification.	119
Figure 4.18 The FTIR pattern of PANI/GNPs (untreated)-DBSA nanocomposites.	120
Figure 4.19 The schematic representation of interactions mechanism between PANI polymer, GNPs nanofiller and DBSA acid as dopant.	122
Figure 4.20 The Raman spectra of PANI/GNPs(untreated)-DBSA with various loading of GNPs nanofiller without surface treatment.	125
Figure 4.21 XRD pattern of PANI/GNPs nanocomposites with various GNPs nanofiller loading synthesized by oxidation polymerization of aniline and DBSA has been used as dopant.	127
Figure 4.22 The plots graph of electrical conductivity of PANI/GNPs without DBSA dopant addition.	130
Figure 4.23 The plots graph of elctrical conductivity of PANI/GNPs (untreated)-DBSA with dopant addition.	131
Figure 4.24 The SEM image of GNPs(treated) at 5000x of magnification.	133
Figure 4.25 The SEM image of PANI/GNPs (treated) with 0.25wt% of GNPs (non covalent) loading at 100x of magnification.	133
Figure 4.26 The SEM image of PANI/GNPs treated with 0.75wt% of GNPs (non covalent) loading at 100x of magnification.	134
Figure 4.27 SEM image of PANI/GNPs treated with 1.00wt% of GNPs (non covalent) loading at 100x of magnification.	134
Figure 4.28 The Pure Ag nanoparticles at 100x of magnification.	136

Figure 4.29 The PANI /GNPs (treated)-Ag with 0.25wt % Ag nanofiller loading at 1000x of magnification. The GNPs (treated) loading was 0.75wt%.	136
Figure 4.30 The PANI /GNPs (treated)-Ag with 1.00 wt % Ag nanofiller loading at 1000x of magnification. The GNPs (treated) loading was 0.75wt%.	137
Figure 4.31 The PANI/GNPs(treated)-DBSA at 100kx of magnification with the 0.25wt% of GNPs nanofiller loadings.	138
Figure 4.32 The PANI/GNPs(treated)-DBSA at 100kx of magnification with 0.50 wt% of GNPs nanofiller loadings.	138
Figure 4.33 a) The PANI/GNPs(treated)-DBSA at 100kx of magnification and b) FESEM-EDX analysis of PANI/GNPs (Treated)-DBSA at 0.75wt% of GNPs treated nanofiller loadings.	140
Figure 4.34 The PANI/GNPs(treated)-DBSA at 100kx of magnification with 1.00wt% of GNPs treated loading.	140
Figure 4.35 a) The PANI/GNPs (treated)/Ag-DBSA at 5kx of magnification with 0.25wt% loading and b) FESEM-EDX analysis of PANI/GNPs (Treated)/Ag-DBSA at 0.25wt% of Ag loading (GNPs loading remain 0.75wt%).	141
Figure 4.36 The PANI/GNPs (treated)/Ag-DBSA at 5kx of magnification with 1.00 wt% of Ag loading.	142
Figure 4.37 The sTEM micrograph of PANI/GNPs(treated)-DBSA with 0.75 wt% loading of GNPs in non covalent surface treatment method at a)120kx magnificant b) 57kx magnificant c) 310kx magnification.	144

Figure 4.38 The PANI/GNPs(treated)/Ag-DBSA hybrid nanocomposites with 0.75wt% loading of GNPs in non covalent method at 310kx magnificant (The Ag loading was 1.00wt%).	145
Figure 4.39 The selected area electron diffraction (SAED) pattern of PANI-DBSA.	146
Figure 4.40 The SAED pattern of PANI/GNPs (non covalent)-DBSA with 0.75wt% treated GNPs loading.	146
Figure 4.41 The SAED pattern of PANI/GNPs-Ag.	147
Figure 4.42 The SAED pattern of Pure Ag.	148
Figure 4.43 The PANI/GNPs(treated)-DBSA with various GNPs nanofiller loadings.	149
Figure 4.44 The schematic representation of interactions mechanism between PANI polymer and non covalent surface treatment of GNPs nanofiller by PEI.	151
Figure 4.45 The FTIR result of PANI/GNPs(treated)/Ag-DBSA with various Ag nanofiller loadings. The GNPs(treated) loading remains 0.75 wt%.	152
Figure 4.46 The comparision between the FTIR spectra of PANI-DBSA, PANI/GNPs (untreated- treated) and PANI with Ag nanofiller.	153
Figure 4.47 The schematic representation of interactions mechanism between PANI/GNPs (treated)-DBSA nanocomposite with Ag nanoparticles.	153
Figure 4.48 The Raman shift of the PANI/GNPs(treated)-DBSA nanocomposites with various loading of GNPs non covalent treated nanofillers.	154
Figure 4.49 The Raman spectroscopy of PANI/GNPs/Ag-DBSA with various Ag loadings.	158
Figure 4.50 The comparison raman spectra of PANI-DBSA, PANI/GNPs(untreated)-DBSA, PANI/GNPs(treated)-DBSA and PANI/GNPs(treated)/Ag-DBSA.	159

Figure 4.51 The XRD pattern of PANI/GNPs with various GNPs loadings. [GNPs nanoparticles have been done for surface modification (non-covalent)].	161
Figure 4.52 The XRD pattern of PANI/GNPs/Ag with various Ag loading. [All treated GNPs loading has been constant at 1.00wt% of loading].	162
Figure 4.53 The XRD pattern comparison for the PANI-DBSA, PANI/GNPs synthesizes by oxidation polymerization & non covalent and PANI/GNPs/Ag nanocomposites samples.	163
Figure 4.54 The electrical conductivity plots of the PANI/GNPs (treated)-DBSA with various loadings of GNPs nanofiller (wt%).	165
Figure 4.55 The electrical conductivity plots of PANI/GNPs (treated)/Ag-DBSA with various Ag nanofiller loading (wt%).	167
Figure 4.56 The enhancement of electrical conductivity of PANI with the presence of GNPs as nanofiller, the DBSA acid as dopant and surface modification of GNPs. The decreased occurs when Ag nanofiller was used. All the conductivity value for the sample GNPs (untreated), GNPs (treated) and Ag was chosen at 0.75wt% loading.	168
Figure 4.57 The CST simulation model of the microstrip patch antenna design.	169
Figure 4.58 The return loss of the recommended rectangular microstrip patch antenna exhibited quality performance having the -23.376 at 2.449 GHz of the resonant frequency.	171
Figure 4.59 The comparison of return loss results between the simulation and experimental measurement	174
Figure 4.60 The gain simulation result for the 2.45Gz.	177
Figure 4.61 The antenna gain of microstrip patch antenna.	179

- Figure 4.62 The free space simulated radiation pattern shows E- field of the dipole shape design antenna. 181
- Figure 4.63 The free space simulated radiation pattern of the H-field shows the dipole pattern of antenna. 181
- Figure 4.64 Vertical radiation pattern for transmitter and receiver shows the dipole pattern of the prototype antenna. 184
- Figure 4.65 The radiation pattern of the H-field shows the dipole pattern of the prototype antenna. 184
- Figure 4.66 The PANI/GNPs (treated)-DBSA reacts with radio waves for a wearable textile antenna. 185



LIST OF SYMBOLS AND ABBREVIATIONS

°C	-	Temperature (celcius)
2D	-	Two dimensional
Ag	-	Silver
C	-	Carbon
CPW	-	Coplanar waveguide
CST	-	Computing Simulation Technology
dB	-	Decibel
DBSA	-	Dedocylbenzene sulfonic acid
EDX	-	Energy dispersive X-ray analysis
EG	-	Ethylene glycol
FTIR	-	Fourier Transform Infrared
GHz	-	Gigahertz for frequency
GNPs	-	Graphene nanoplatelets
kx	-	Magnification
N	-	Nitrogen
nm	-	nanometer
O	-	Oxygen
PANI	-	Polyaniline
PEI	-	polyethylenimine
PVP	-	Polyvinyl Pyrrolidones
RF	-	Radio Frequency
S/cm	-	Unit for Electrical conductivity (siemens per centimeter)
S ₁₁	-	Reflection coefficient
SMA	-	SubMiniature version A connector
Sp ²	-	Lattice Structure
VSWR	-	Voltage Standing Wave Ratio
WBAN	-	Wireless Body Area Networks
WLAN	-	Wireless local-area network