HIGHLY CONDUCTIVE ANTENNA BASED ON GNP/Ag/Cu NANOCOMPOSITE FOR WEARABLE APPLICATION

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A thesis submitted
in fulfillment of the requirements for the degree of
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2024

DECLARATION

I declare that this thesis entitled “Highly Conductive Antenna Based on GNP/Ag/Cu Nanocomposite for Wearable Application” 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 : NOR HADZFIZAH BINTI MOHD RADI

Date : 11/10/2024

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 Doctor of Philosophy.

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Signature :.....

Supervisor Name : IR. DR. MOHD MUZAFAR BIN ISMAIL

Date : 11/10/2024

DEDICATION

To my beloved family

ABSTRACT

This research addresses the growing need for innovative new formulation nanocomposite material for highly conductive wearable antenna and useful solutions in areas such as public safety, navigation, and mobile computing. This study explores the impact potential of a new formulation of Graphene Nanoplatelet/Silver/Copper (GNP/Ag/Cu) nanocomposite formulation for low range Ultrawide Band (UWB) applications, aiming to overcome the limitations of traditional copper-based antennas. The research employs silk-screen printing technology to fabricate conductive patches of GNP/Ag/Cu nanocomposite onto textile substrates. Various loading levels of Graphene Nanoplatelets (GNP) are tested to evaluate their impact on the radiating properties of the nanocomposite. Electrical conductivity is measured using the four-point probe method, while morphological and compositional analyses are conducted via scanning electron microscopy (SEM) and energy-dispersive X-ray spectroscopy (EDS). The performance of the antennas is assessed in terms of gain, return loss, and Specific Absorption Rate (SAR), with comparisons drawn between different textile substrates (leather, cotton, and felt). The GNP/Ag/Cu nanocomposite conductive ink exhibits increased electrical conductivity to be superconductive with additional layers, reaching up to 40.218 $\times 10^7$ S/m in the fifth layer. The antennas fabricated with these materials demonstrate higher gains of 11.7 dB, 11.8 dB, and 12.2 dB for leather, cotton, and felt substrates, respectively, with return losses consistently below -20 dB. The SAR values, evaluated for an input power of 0.5 W and based on 10 grams of human tissue, show compliance with ICNIRP standards, remaining below 2 W/kg. The improved conductivity and performance of the GNP/Ag/Cu nanocomposites validate their effectiveness as a substitute for copper in wearable antennas. The synergistic effects of GNP, Ag, and Cu enhance electrical conductivity to be superconductive and enhance overall antenna gain while maintaining safety standards. The morphological data from SEM and EDS highlight the uniformity and thickness of the nanocomposite coating, which contributes to the antenna's improved performance. This study provides a significant advancement in the development of wearable antennas by leveraging the unique properties of graphene and its composites. The successful integration of GNP/Ag/Cu nanocomposites into textile substrates offers a promising alternative to conventional copper-based solutions, addressing issues related to cost, flexibility, and environmental impact. The findings support the potential of these materials in enhancing the functionality of wearable technologies and contribute valuable insights for future research and development in smart textile antennas.

ANTENA BERKONDUKSI TINGGI BERASASKAN NANOKOMPOSIT GNP/Ag/Cu UNTUK APLIKASI BOLEH PAKAI

ABSTRAK

Penyelidikan ini menangani keperluan yang semakin meningkat untuk penyelesaian formulasi baru material nanokomposit konduktif tinggi untuk antena boleh pakai yang inovatif dalam bidang seperti keselamatan awam, navigasi, dan pengkomputeran mudah alih. Kajian ini meneroka potensi formulasi nanokomposit Graphene Nanoplatelet/Perak/Kupur (GNP/Ag/Cu) untuk aplikasi julat rendah Ultrawide Band (UWB), bertujuan untuk mengatasi kekangan antenna yang konvensional berasaskan tembaga. Penyelidikan ini menggunakan teknologi percetakan skrin sutera untuk menghasilkan tampalan konduktif nanokomposit GNP/Ag/Cu pada substrat tekstil. Pelbagai tahap pemuatan Graphene Nanoplatelets (GNP) diuji untuk menilai kesannya terhadap sifat radiasi nanokomposit tersebut. Konduktiviti elektrik diukur menggunakan kaedah probe empat titik, manakala analisis morfologi dan komposisi dilakukan melalui mikroskop elektron imbasan (SEM) dan spektroskopi sinar-X pengedaran tenaga (EDS). Prestasi antena dinilai dari segi gain, return loss, dan Kadar Penyerapan Spesifik (SAR), dengan perbandingan dilakukan antara substrat tekstil yang berbeza (kulit, kapas, dan felt). Nanokomposit GNP/Ag/Cu menunjukkan peningkatan superkonduktiviti elektrik dengan lapisan tambahan, mencapai sehingga 40.218 × 10^7 S/m pada lapisan kelima. Antena yang dihasilkan dengan bahan ini menunjukkan gain sebanyak 11.7 dB, 11.8 dB, dan 12.2 dB untuk substrat kulit, kapas, dan felt, masing-masing, dengan return loss yang konsisten di bawah -20 dB. Nilai SAR, yang dinilai untuk kuasa input 0.5 W dan berdasarkan 10-gram tisu manusia, menunjukkan pematuhan dengan piawaian ICNIRP, kekal di bawah 2 W/kg. Peningkatan konduktiviti dan prestasi nanokomposit GNP/Ag/Cu mengesahkan keberkesanan mereka sebagai pengganti tembaga dalam antena boleh pakai. Kesan sinergistik GNP, Ag, dan Cu meningkatkan konduktiviti elektrik dan gain keseluruhan antena sambil mengekalkan piawaian keselamatan. Data morfologi dari SEM dan EDS menyerlahkan keseragaman dan ketebalan salutan nanokomposit, yang menyumbang kepada prestasi antena yang lebih baik. Kajian ini memberikan kemajuan yang signifikan dalam pembangunan antena boleh pakai dengan memanfaatkan sifat unik graphene dan kompositnya. Integrasi berjaya nanokomposit GNP/Ag/Cu ke dalam substrat tekstil menawarkan alternatif yang menjanjikan kepada penyelesaian berasaskan tembaga konvensional, menangani isu berkaitan kos, fleksibiliti, dan impak persekitaran. Penemuan ini menyokong potensi bahan-bahan ini dalam meningkatkan fungsi teknologi boleh pakai dan menyumbang pandangan berharga untuk penyelidikan dan pembangunan masa depan dalam antena tekstil pintar.

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My personal expression during the writing process.

"*As I spent many thoughtful hours in my room. Most of the time ~ staring at my PC, it can seem almost like the definition of wasted time, procrastination and with no purpose. But it is more than that. It is actually an exercise in discovering the contents of our own minds. It is easy to imagine that we know what we think but we rarely do entirely. If we doing right, staring at the PC offers a way for us to listen to the quieter suggestions and perspectives of our deep inside selves."*

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LIST OF ABBREVIATIONS

AUT	-	Antenna Under Test
CPW	-	Co-planar Waveguide
CST	-	Computer Simulation Technology
EDS	-	Energy Dispersive X-ray Spectroscopy
FCC	-	Federal Communications Commission
FTKEK	-	Faculty of Electronics & Computer Technology & Engineering
FR4	-	Flame Retardant Glass Epoxy Laminate
GNP	-	Graphene Nanoplatelet
GO	-	Graphene Oxide
ICNIRP	-	International Commission on Non-Ionizing Radiation Protection
OCP	-	Open-ended Coaxial Probe
PCB	-	Printed Circuit Board
RF	-	Radio Frequency
RL	-	Return Loss
SAR	-	Specific Absorption Rate
SEM	-	Scanning Electron Microscopy
UTeM	-	Universiti Teknikal Malaysia Melaka
UWB	-	Ultra-wide Band
VNA	-	Vector Network Analyzer
VSWR	-	Voltage Standing Wave Ratio
WBAN	-	Wireless Body Area Network

LIST OF SYMBOLS

Ag	-	Silver
Cu	-	Copper
AgNS	-	Silver Nanosheets
ε_r	-	Relative Permittivity
tan δ	-	Loss tangent
σ	-	Conductivity
ρ	-	Resistivity
℃	-	Degree celcius
w %	-	Weight Percent
dB	-	Decibel
dBi	-	Decibels Relative to Isotropic
Ω	-	Ohm

LIST OF APPENDICES

LIST OF PUBLICATIONS

The followings are the list of publications related to the work on this thesis:

Radi, N.H.M., Ismail, M.M., Zakaria, Z., Abd Razak, J. and Abdullah, S.N.I., 2022. Development and design of wearable textile antenna on various textile substrate for unlicensed ultra-wideband applications. *TELKOMNIKA (Telecommunication Computing Electronics and Control),* 20(6), pp.1181-1188. (SCOPUS indexed).

Abdullah, S.N.I., Ismail, M.M., Abd Razak, J., Zakaria, Z., Ab Rashid, S.R. and Radi, N.H.M., 2022. Design of triple band antenna for energy harvesting application. *Bulletin of Electrical Engineering and Informatics,* 11(4), pp.2359-2367. (SCOPUS indexed).

Radi, N.H.M., Ismail, M.M., Zakaria, Z. and Abd Razak, J., 2022. The Performance Comparison between CPW-fed and Microstrip Feedline Leather Antenna for UWB Applications. *Proceedings of 4th International Conference on Telecommunication, Electronic and Computer Engineering (ICTEC'22),* pp.98-99

Radi, N.H.M., Ismail, M.M., Zakaria, Z. and Abd Razak, J., 2024. The effect of thickness of a conductive nanocomposite ink printed on textile co-planar waveguide antenna. *Bulletin of Electrical Engineering and Informatics,* 13(1), pp.208-214. (SCOPUS indexed)

CHAPTER 1

INTRODUCTION

1.1 Background

The popularity of wearable antennas is on the rise due to their compactness, reconfigurability, flexibility, and durability, making them suitable for various wireless communication applications. Their versatility extends to diverse fields, including medical, sports, military, and beyond, underscoring their immense the possibility exists for a variety of applications. (Ashyap et al., 2017; Sabban, 2018, 2019, 2020a, 2020b; Khajeh-Khalili, Haghshenas and Shahriari, 2020; Khajeh-Khalili, Shahriari and Haghshenas, 2021; Bahmanzadeh and Mohajeri, 2022). In medical applications, wearable antenna systems play a significant role in keeping track of body performance while exercising, as well as keeping track of important signs such as heart rate and blood pressure. These systems serve medical professionals in assessing patient health and facilitating timely interventions. Additionally, they contribute to broader network connectivity, enabling data transmission for remote monitoring and analysis beyond the medical facility setting (Ashyap et al., 2017; Sabban, 2018; Khajeh-Khalili, 2021). Furthermore, wearable antennas, also known as body-worn antennas, are gaining significant attention due to their comfort and versatility. Textiles have emerged as a promising substrate for these antennas, allowing for integration into clothing and accessories. A variety of textiles, including cotton (Tan et al., 2018), denim (Jalil et al., 2012), leather (Ahmed, Ahmed and Shaalan, 2017), and drill fabric (Jamal et al., 2024), have been investigated for their suitability as substrates for wearable antennas. This diversity in

textile options enables customization to suit different applications and preferences, making wearable antennas more accessible and practical for everyday use (Jalil et al., 2012; Mahmud, Jabri and Mahjabeen, 2013; Ahmed, Ahmed and Shaalan, 2017; Tan et al., 2018; Regina and Merline, 2021; Salman et al., 2022) . In this study proposed the wearable highly conductive and textile antenna that covering the UWB bands.

This research aims to evaluate the potential of a new formulation of Graphene Nanoplatelet/Silver/Copper (GNP/Ag/Cu) conductive nanocomposites for a new type UWB flexible wearable leather antenna. Silk-screening printing technology will be applied to incorporate GNP/Ag/Cu nanocomposites for highly conductive radiating patch and implemeting the Co-planar Waveguide (CPW) ground plane antenna fabrication. The impact of GNP loading on the antenna radiating properties for GNP/Ag/Cu-textiles nanocomposites will be studied and the evaluation is carried out using standard physical and electrical characterization methods. These methods may include measurements of electrical conductivity, dielectric properties, antenna radiation patterns, impedance matching, and resonant frequencies. By systematically varying the GNP loading and analyzing its effects on these properties, researchers can gain insights into the optimal formulation for achieving desired antenna performance characteristics in GNP/Ag/Cu-textiles nanocomposites.

Previously, copper was commonly used to construct the conductive patch of an antenna, which posed several challenges. Copper was expensive, bulky, environmentally sensitive, and difficult to manufacture. These limitations hindered the widespread adoption and practical implementation of antenna technologies, particularly in applications where cost-effectiveness, lightweight design, environmental sustainability, and ease of manufacturing were crucial factors (Mohd Zaini and Abdul Rani, 2018). Because graphene