DESIGN AND DEVELOPMENT OF A FLEXIBLE MICROSTRIP MULTI-RESONATOR FOR WEARABLE CHIPLESS RFID TAG APPLICATIONS

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MASTER OF SCIENCE IN ELECTRONICS ENGINEERING

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Faculty of Electronics and Computer Technology and Engineering

Design and Development of a Flexible Microstrip multi-resonator for Wearable Chipless RFID Tag Applications

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UNIVERSITI TEKNIKAL MALAYSIA MELAKA

A thesis submitted
in fulfillment of the requirements for the degree of
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2025

DECLARATION

I declare that this thesis entitled "Design and Development of a Flexible Microstrip multi-resonator for Wearable Chipless RFID Tag Applications " 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 :..

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Date : 26/02/2025

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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 electronics engineering.

Signature : ....

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Date : 26/02/2025

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DEDICATION

To my beloved mother, whose unwavering love, prayers, and sacrifices have been my greatest strength and motivation. Your endless support and encouragement have guided me through every challenge.

And to my late father, whose wisdom, kindness, and dreams continue to inspire me. Though you are no longer with me, your values and teachings remain a guiding light in my life. This work is a tribute to your memory and all that you instilled in me.

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ABSTRACT

Chipless Radio Frequency Identification (CRFID) is gaining attention as a low-cost and flexible alternative to traditional RFID, particularly for applications in wearable electronics and smart textiles. Unlike conventional RFID, which relies on integrated circuits, CRFID utilizes passive resonators for data encoding. However, existing flexible and fabric-based CRFID implementations often suffer from low bit capacity, poor spectral efficiency, and poor-quality factor (Q-factor), limiting their practical application. This research introduces a Parallel L-shape Multi-Resonator (PLMR) design aimed at enhancing bit encoding capacity, spectral density, and overall performance. The study begins with a detailed review of microstrip resonators, textile-integrated CRFID designs, and high-Q resonator structures. A theoretical model of the PLMR-based CRFID tag is developed and refined through electromagnetic simulations using CST Microwave Studio 2022 and Advanced Design System 2023.To validate the proposed design, Prototypes were fabricated on two different types of substrates: rigid (Rogers 4003C) and flexible (AN10 Kapton). Textile-based materials such as pile, denim, felt, silk, and fleece were evaluated solely through thorough simulations. The performance of the design have been evaluated using key metrics such as coding capacity, spectral density, spatial density, and Q-factor. The fabricated prototypes have bit capacities of 15 on Rogers 4003C and 9 on AN10 Kapton. In contrast, fabric-based designs achieved a simulated bit capacity of 13 for all evaluated textile types. The design achieves high-Q value of 237.3 on Roger 4003C, 51.5 on AN10 Kapton and 278 on fleece fabric substrate. Due to high Q-value, resonator structure improves frequency selectivity, minimizes interference, and enhances detection accuracy, thereby extending the tag's operational range. Performance validation through S-parameter analysis, frequency response measurement, and Bending analysis examination confirms its reliability for practical applications. The results demonstrate that the PLMR-based CRFID tag provides superior flexibility, increased data encoding capacity, and robust signal performance, positioning it as a viable solution for next-generation chipless RFID technologies. This work contributes to the advancement of wearable and textile-integrated RFID systems, opening new possibilities for automated tracking, identification, and sensing in smart environments.

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REKA BENTUK DAN PEMBANGUNAN MIKROSTRIP BERBILANG RESONATOR FLEKSIBEL UNTUK APLIKASI TAG RFID TANPA CIP BOLEH DIPAKAI

ABSTRAK

Pengenalpastian Frekuensi Radio Tanpa Cip (Chipless Radio Frequency Identification, CRFID) semakin mendapat perhatian sebagai alternatif kos rendah dan fleksibel kepada RFID konvensional, terutamanya untuk aplikasi dalam elektronik boleh pakai dan tekstil pintar. Tidak seperti RFID konvensional yang bergantung kepada litar bersepadu, CRFID menggunakan resonator pasif untuk pengekodan data. Namun begitu, pelaksanaan CRFID fleksibel dan berasaskan fabrik yang sedia ada sering mengalami kekangan dari segi kapasiti bit yang rendah, kecekapan spektrum yang lemah, serta faktor kualiti (Q-factor) yang rendah, sekali gus mengehadkan aplikasi praktikalnya. Kajian ini memperkenalkan reka bentuk Resonator Berbilang Bentuk-L Selari (Parallel L-shape Multi-Resonator, PLMR) yang bertujuan untuk meningkatkan kapasiti pengekodan bit, ketumpatan spektrum, dan prestasi keseluruhan sistem. Kajian dimulakan dengan ulasan terperinci mengenai resonator mikrostrip, reka bentuk CRFID bersepadu tekstil, dan struktur resonator berkualiti tinggi (high-Q). Seterusnya, satu model teori bagi tag CRFID berasaskan PLMR dibangunkan dan diperhalusi melalui simulasi elektromagnetik menggunakan CST Microwave Studio 2022 dan Advanced Design System 2023. Bagi mengesahkan reka bentuk yang dicadangkan, prototaip telah dibina pada dua jenis substrat berbeza: substrat tegar (Rogers 4003C) dan substrat fleksibel (AN10 Kapton). Bahan berasaskan tekstil seperti kain berbulu (pile), denim, felt, sutera, dan fleece pula dinilai secara eksklusif melalui simulasi terperinci. Prestasi reka bentuk dinilai berdasarkan metrik utama seperti kapasiti pengekodan, ketumpatan spektrum, ketumpatan ruang, dan faktor-Q. Prototaip yang dibina mencatatkan kapasiti bit sebanyak 15 pada Rogers 4003C dan 9 pada AN10 Kapton. Sebaliknya, reka bentuk berasaskan fabrik mencapai kapasiti bit simulasi sebanyak 13 bagi semua jenis tekstil yang dinilai. Reka bentuk ini juga mencapai nilai Q yang tinggi, iaitu 237.3 pada Rogers 4003C, 51.5 pada AN10 Kapton, dan 278 pada substrat fabrik fleece. Dengan nilai Q yang tinggi ini, struktur resonator memperbaiki selektiviti frekuensi, meminimumkan gangguan, dan meningkatkan ketepatan pengesanan, sekali gus memperluas julat operasi tag tersebut. Pengesahan prestasi melalui analisis parameter-S, pengukuran tindak balas frekuensi, dan analisis lenturan membuktikan kebolehpercayaannya untuk aplikasi dunia sebenar. Hasil kajian menunjukkan bahawa tag CRFID berasaskan PLMR menawarkan fleksibiliti unggul, peningkatan kapasiti pengekodan data, dan prestasi isyarat yang kukuh, menjadikannya satu penyelesaian yang berdaya maju bagi teknologi RFID tanpa cip generasi akan datang. Kajian ini menyumbang kepada kemajuan sistem RFID boleh pakai dan bersepadu tekstil, sekali gus membuka peluang baharu dalam penjejakan automatik, pengecaman, dan penderiaan dalam persekitaran pintar.

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LIST OF ABBREVIATIONS

ABBRIVATIONS		DESCRIPTION
CRFID	-	Chipless Radio Frequency Identification
WRFID	-	Wearable Radio Frequency Identification
PLMR	-	Parallel L-shape Multi-Resonator
Q-F	-	Quality Factor
TDR	-	Time Domain Reflectometry
RCS	-	Radar Cross Section
PCB	-	Printed Circuit Board
UWB	-	Ultra Wide Band
SAW	-	surface acoustic wave
CST	-	Computer Simulated Software
ADS	-	Advance Design System
UHF	-	Ultra High Frequency
CSRR	-	Complementary Split Ring Resonators
OOK	-	On-Off Keying
FSK	-	Frequency Shift Coding
PET	-	Polyethylene Terephthalate
BAN	-	Body Area Networks
FD	-	Frequency-domain
VNA	-	Vector Network Analyzer
SD	-	spectral density
SPD	-	spatial density

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TLs	-	Transmission lines
RF	-	Radio Frequency

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LIST OF SYMBOLS

SYMBOLS		DESCRIPTION
ε_r	-	Dielectric constant
$Tan\delta$	-	Tangent loss
f_0	-	Center frequency
Ω	-	Ohm
cm^2	-	Centimeter Square
mm^2	-	Millimeter Square
BW	-	Bandwidth
dB	-	Decibel

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LIST OF PUBLICATIONS

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

Sanaullah Khan, A K M Zakir Hossain, S. M. Kayser Azam, Mohamadariff Othman, Nurulhalim Bin Hassim "Design Prospects of Parallel U-shaped Multi Resonator for Fabric-based Chipless RFID Tags" 4th International Conference on Innovations in Power and Advanced Computing Technologies, i-PACT-2023, Kuala Lampur, Malaysia.

Sanaullah Khan, A. K. M. Zakir Hossain , Nurulhalim Bin Hassim and Muhammad Inam Abbasi"An RCS based Planar Parallel V-Shaped Multi Resonators for Wearable Chipless RFID Application" IEEE 22nd Student Conference on Research and Development (SCOReD),UiTM, Shah Alam, Malaysia, 2024

Sanaullah Khan, Mujeeb Abdullah, A. K. M. Zakir Hossain and Saad Hassan Kiani "Dual-band S-Shaped mmWave MIMO Antenna System for Ka-band Applications" IEEE 22nd Student Conference on Research and Development (SCOReD), UiTM, Shah Alam, Malaysia, 2024

A K M Zakir Hossain, Sanaullah, Md. Kayser Azam, Muhammad ibn Ibrahimy "Investigation on the Planar Resonator for Fabric Based Chipess RFID" 9th International Conference on Computer and Communication Engineering (ICCCE), Kuala Lampur, Malaysia, 2023

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CHAPTER 1

INTRODUCTION

1.1 Background

RFID (Radio Frequency Identification) plays a vital role in modern industries by offering a highly efficient and accurate way to automate identification, tracking, and data management processes. Its ability to function without the need for line-of-sight scanning makes it superior to traditional methods than barcodes, because barcode need line-of-sight, Risk of susceptibility to damage, and vulnerability to tampering (Finkenzeller, Klaus, 2010). RFID technology allowing for real-time tracking and management of assets, inventory, and individuals (Dobkin, David M., 2006). RFID can store significant amounts of data, ensuring that each tag carries detailed information, which is critical for complex applications such as supply chain management, healthcare, and retail (Finkenzeller, K., 2004). The technology also enhances security by enabling encrypted communication and authentication, reducing the risks of counterfeiting and unauthorized access (Mulloni, V. & Donelli, M., 2020).

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Wearable RFID (WRFID) tags further advance this technology by embedding RFID capabilities into clothing, accessories, and other wearable items, unlocking a range of new possibilities. WRFID tags provide real-time monitoring in applications like healthcare, where they are used for patient tracking, medication management, and monitoring vital signs, ensuring safety and accuracy (Mulloni & Donelli, 2020). In industrial settings, WRFID tags improve worker safety by tracking movements in hazardous areas and optimizing workflows (Karmakar, Vena & Costa, 2016). In sports and fitness, these tags allow for the monitoring of performance metrics such as speed, distance, and heart rate, helping athletes improve their training regimens. Additionally, in retail, wearable RFID tags enable personalized shopping experiences, such as interactive fitting rooms that recognize tagged items and provide suggestions (Preradovic & Balbin, 2010). Lightweight, compact, and easy to integrate, WRFID tags enhance convenience and comfort while offering seamless, contactless interactions, making them particularly valuable in a world increasingly focused on efficiency and connectivity.

1.1.1 Radio-Frequency Identification

RFID refers to a method of conveniently retrieving data and identifying an object using electromagnetic radiation. It uses electromagnetic frequency signals to communicate information from the RFID reader to the RFID tag (Want, 2006). Basic blocks of conventional RFID system as illustrated in the figure 1.1 comprises of three basic elements; the RFID tag or transponder that contains the code; an RFID reader or interrogator that sends signals to the tag to read it; and a middleware application that manages the computer windows accessible by the software for encoding the information received from the reader and decoding it into computer (Juels, 2006).

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In 1948, Stockman (Roberts, 2006) first proposed RFID in his historic article, "Communication by Means of Reflected Power". According to Stockman, modulation can be achieved by varying the amount of reflected power through the tag antenna's load (a process known as "antenna load modulation"). Today, RFID is the name given to this latest generation of wireless technology. Ever since, engineers and academics have been attempting to create inexpensive RFID systems.

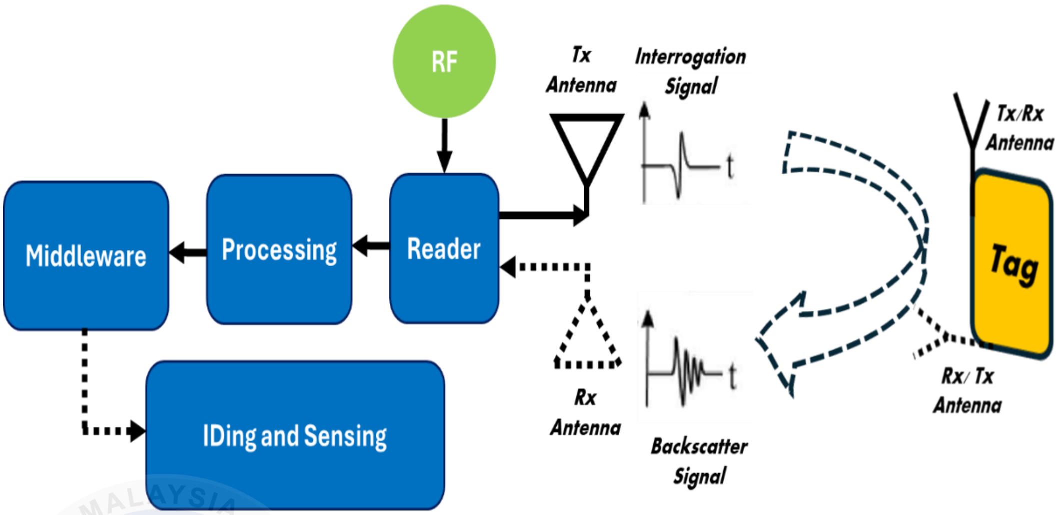

Figure 1.1. Block diagram of Convensional RFID System

RFID is One of the branches of the Auto Identification system, and currently, its application is widespread in a different industry, including inventory management, library operations, toll collection, and item identification and localization etc (Jia et al., 2012), as illustrated in figure 1.2.

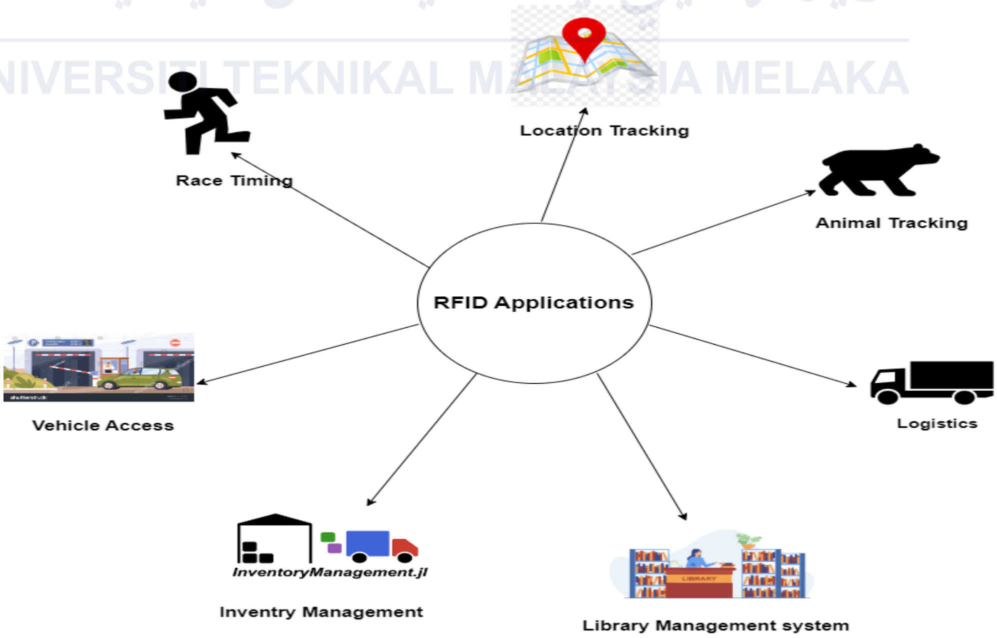

Figure 1.2. Application of RFID (Jia et al., 2012)

1.1.2 Classification of RFID tags

RFID tags can be classified in various ways, one such classification is based on tag's power source: Active tags are those which operate entirely on batteries; semi-active tags are those that operate on batteries to some extent; and passive tags do not operate on batteries. Because of their intrinsic costs, active and semi-active or semi-passive RFID classes are not appropriate barcode system replacements (Rao, Nikitin & Lam, 2005). Under the passive RFID category there are two types, Chipped and chipless RFID. RFID chips with SHF/UHF antennas are used in the majority of sensing and tracking applications, which leads to their high cost. But researchers are looking more closely into chipless RFID (CRFID) in an effort to reduce the cost of passive RFID. in CRFID technology uses Microwave multi-resonators for encoding instead of traditional chip to reduce the Cost (Chen et al., 2019; Zakir Hossain et al., 2023).

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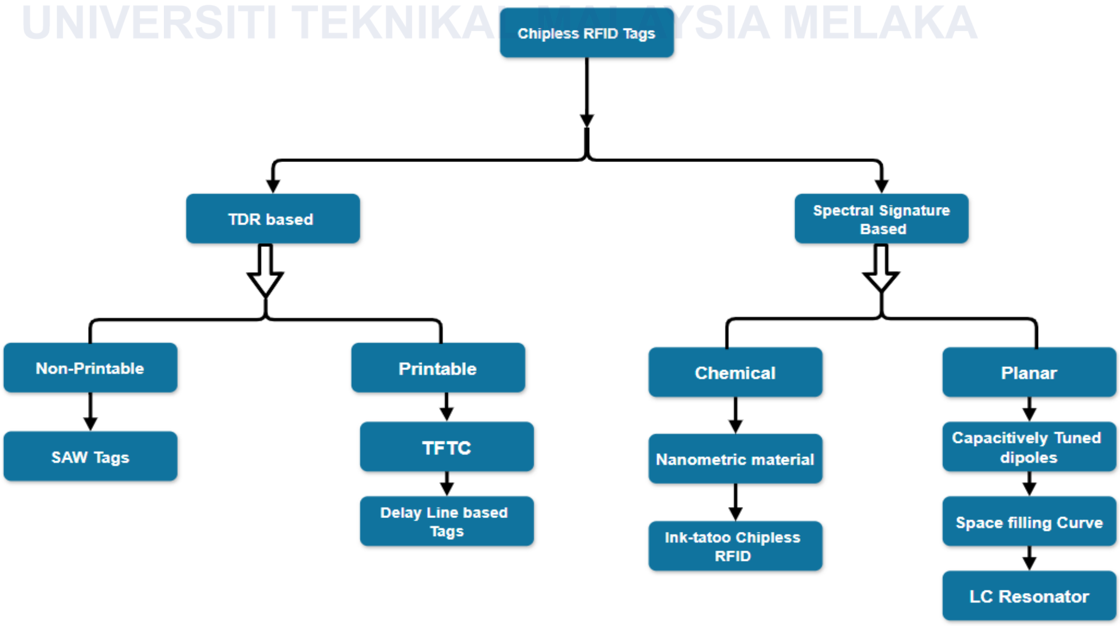

Figure 1.3. Classification of CRFID Tags