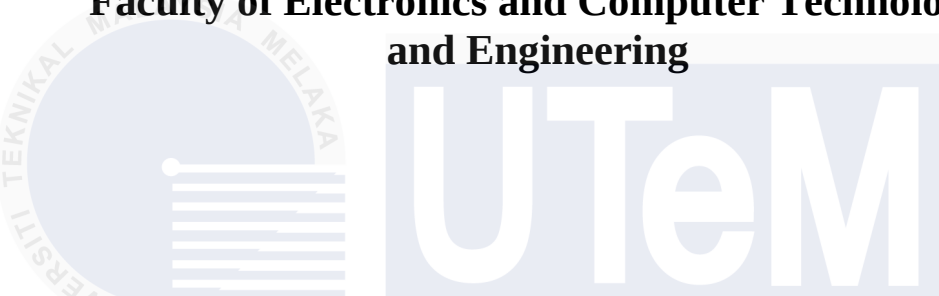




**Faculty of Electronics and Computer Technology
and Engineering**



**HIGH-Q FACTOR OF SPLIT RING RESONATOR DEFECTED
GROUND STRUCTURE OF MICROWAVE SENSOR FOR
MATERIAL CHARACTERIZATION**

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

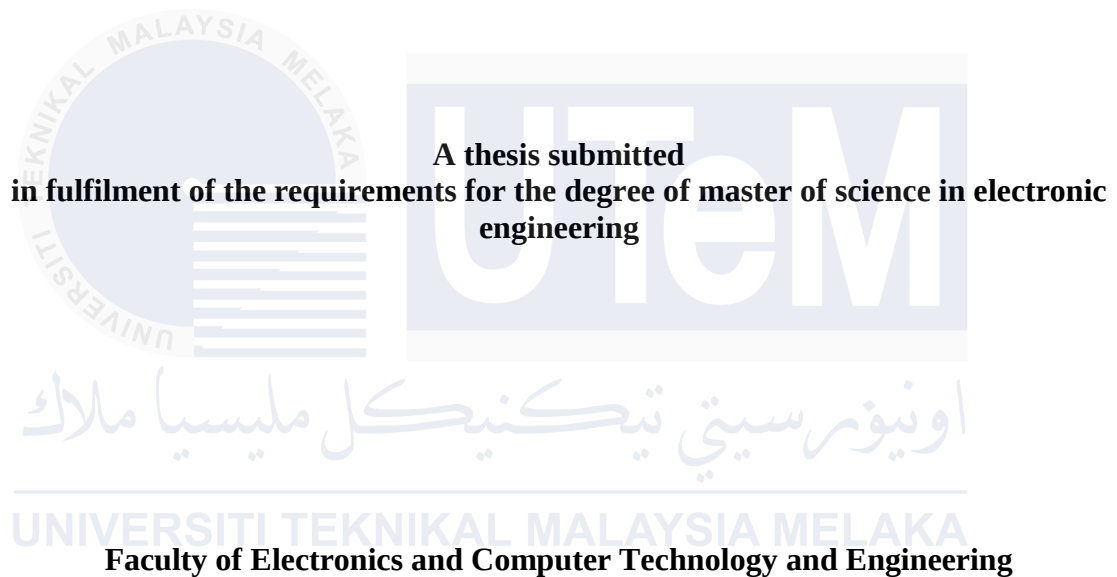
RAYAN AHMED MOHAMMED BA AMER

MASTER OF SCIENCE IN ELECTRONIC ENGINEERING

2025

**HIGH-Q FACTOR OF SPLIT RING RESONATOR DEFECTED GROUND
STRUCTURE OF MICROWAVE SENSOR FOR MATERIAL
CHARACTERIZATION**

RAYAN AHMED MOHAMMED BA AMER

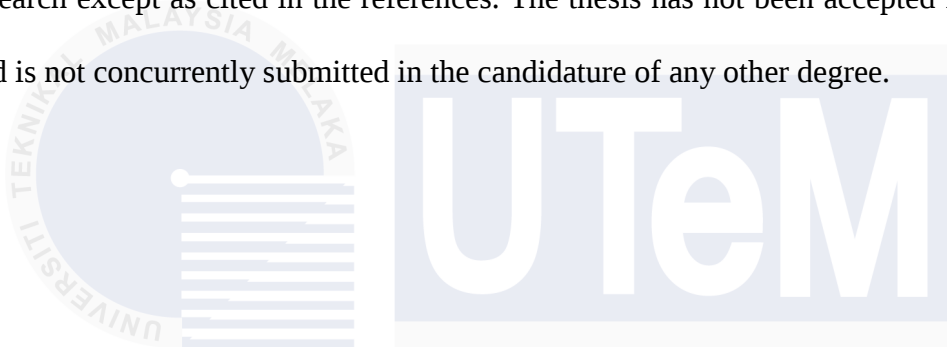


UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2025

DECLARATION

I declare that this thesis entitled “High-Q Factor of Split Ring Resonator Defected Ground Structure of Microwave Sensor for Material Characterization” 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 the candidature of any other degree.



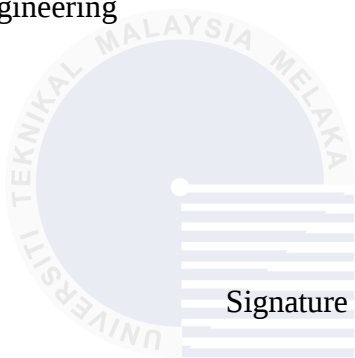
Signature :

Name : Rayan Ahmed Mohammed Ba Amer

Date : 28/3/2025

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 the degree of Master of Science in Electronic Engineering



Signature

:

Supervisor Name

:

Ts. Dr. Maizatul Alice Meor Said

Date

:

30/3/2025

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

DEDICATION

To my beloved parents and siblings



ABSTRACT

Material characterization technologies require high accuracy sensors to meet the industrial specification in producing a reliable and safe product for human use. The existing microwave sensors using conventional microwave resonator such as waveguide, dielectric, and coaxial resonators have been used to characterize materials because they offer a high-quality factor (Q-factor) and great precision. However, they have a complicated structure and process, large and expensive to build. Recently, the planar resonant methods have become the most preferred approach because their simple structure and easy fabrication process. However, the low Q-factor value of this method cause a poor sensitivity and limit its applications. To overcome the limited quality factor, this project integrates the defected ground structure (DGS) technique into the split ring resonator (SRR) Microwave sensor to present new structures of high Q-factor microwave sensors based on defected ground structure split ring resonator (DGS SRR) for detecting and characterizing solid materials. This proposed sensor operated at 2.4 GHz where the solid samples characterization range resonate at 2.0 to 2.5 GHz with reference design SRR sensor operate at 2.5 GHz. The sensors were fabricated using RT/Duroid Roger 5880 as the substrate, characterized by a dielectric constant of 2.2, a loss tangent of 0.0009, and a copper thickness of 17.5 μm . The samples are placed at the maximum concentration of electrical field (E-Field) area where the maximum E-field area is the most sensitive area to observe the dielectric changes. The sensors are designed using computer simulation technology (CST) software and examined with a vector network analyzer (VNA). The resonator structure design is based on the mathematical equation and optimization of the parameters value. As a result, the DGS implementation has increase the Q-factor significantly from 190 to 357 this DGS SRR sensor generates narrow resonance frequency at 2.408 GHz with return loss equal to -17.54 dB. For validation, various solid materials have been used such as RO5880, RO4350 and FR-4 with dielectric constant equal to 2.2, 3.48 and 4.4 respectively. In addition, a detailed dielectric property analysis has been carried out in order to derive a mathematical equation to extract and characterize the materials with unknown dielectric properties. This sensor suits the need of various industrial applications such as the food industry, quality control, bio-sensing medicine, and pharmacy applications due to its capability to identify material characteristics with high Q-factor.

FAKTOR Q TINGGI BAHARU PADA STRUKTUR PEMBUMIAN TERCELA PENYALUN GELANG TERPISAH UNTUK PENDERIA GELOMBANG MIKRO YANG BERKEPEKAAN TINGGI

ABSTRAK

Teknologi pencirian bahan memerlukan penderia ketepatan tinggi untuk memenuhi spesifikasi industri dalam menghasilkan produk yang boleh dipercayai dan selamat untuk kegunaan manusia. Walau bagaimanapun, penderia gelombang mikro sedia ada yang menggunakan penyalun gelombang mikro konvensional seperti gelombang pandu, dielektrik, dan penyalun sepaksi telah digunakan untuk mencirikan bahan kerana ia menawarkan faktor kualiti (faktor Q) yang tinggi dan ketepatan yang baik. Namun begitu, ia mempunyai struktur dan proses yang rumit, bersaiz besar, serta kos pembinaan yang mahal. Baru-baru ini, kaedah salunan planar telah menjadi pendekatan yang paling digemari kerana struktur yang ringkas dan proses fabrikasi yang mudah. Walau bagaimanapun, nilai faktor Q yang rendah bagi kaedah ini menyebabkan sensitiviti yang kurang dan menghadkan aplikasinya. Untuk mengatasi keterbatasan faktor kualiti ini, projek ini mengintegrasikan teknik struktur pembumian tercela ke dalam penderia gelombang mikro penyalun gelang terpisah (SRR) untuk memperkenalkan struktur baharu penderia gelombang mikro faktor Q tinggi berdasarkan penyalun gelang terpisah struktur pembumian tercela (DGS SRR) bagi mengesan dan mencirikan bahan pepejal. Penderia yang dicadangkan ini beroperasi pada 2.4 GHz dalam julat 2 GHz hingga 2.5 GHz untuk pencirian bahan pepejal dengan reka bentuk rujukan penderia SRR beroperasi pada 2.5 GHz. Penderia ini difabrikasi menggunakan RT/Duroid Roger 5880 sebagai substrat, dengan pemalar dielektrik sebanyak 2.2, tangent kehilangan 0.0009, dan ketebalan tembaga 17.5 μm . Sampel diletakkan di kawasan penumpuan medan elektrik maksimum, di mana kawasan medan elektrik maksimum adalah kawasan paling sensitif untuk memerhatikan perubahan dielektrik. Penderia ini direka menggunakan perisian teknologi simulasi komputer (CST) dan diuji dengan penganalisis rangkaian vektor (VNA). Reka bentuk struktur penyalun adalah berdasarkan persamaan matematik dan pengoptimuman nilai parameter. Hasilnya, pelaksanaan DGS telah meningkatkan faktor Q dengan ketara daripada 190 kepada 357. Penderia DGS SRR ini menghasilkan frekuensi salunan yang sempit pada 2.408 GHz dengan kehilangan pantulan sama sebanyak -17.54 dB. Untuk tujuan pengesahan, pelbagai bahan pepejal telah digunakan seperti RO5880, RO4350, dan FR-4 dengan pemalar dielektrik masing-masing sebanyak 2.2, 3.48, dan 4.4. Selain itu, analisis sifat dielektrik yang terperinci telah dijalankan untuk memperoleh persamaan matematik bagi mengekstrak dan mencirikan bahan dengan sifat dielektrik yang tidak diketahui. Penderia ini memenuhi keperluan pelbagai aplikasi industri seperti industri makanan, kawalan kualiti, penderia-bioperubatan, dan aplikasi farmasi kerana kemampuannya untuk mengenal pasti ciri-ciri bahan dengan faktor Q yang tinggi.

ACKNOWLEDGMENTS

In the name of Allah, the Most Gracious and the Most Merciful. Alhamdulillah, I praise and thank Allah SWT for His greatness and for giving me the strength and courage to complete this thesis.

I would like to express my deepest gratitude and heartfelt appreciation to my supervisor, Dr. Maizatul Alice Meor Said, from the Faculty of Electronic and Computer Engineering at Universiti Teknikal Malaysia Melaka (UTeM). His exceptional guidance, steadfast support, and unwavering encouragement have been instrumental in the successful completion of this thesis.

I would also like to convey my utmost gratitude to Dr. Noor Azwan Bin Shairi, a cosupervisor and project leader of this research project hailing from the Faculty of Electronic and Computer Engineering. His crucial supervision, unwavering support, patient guidance, invaluable suggestions, and his willingness to generously dedicate his time have all been deeply appreciated throughout this research endeavour.

Special great appreciation to my beloved mother, father and siblings for their support and encouragement in completing this degree.

I would like to extend my gratitude to the department and faculty members for their assistance and support during this research. Additionally, I am thankful to my friends who provided me with support throughout this endeavor. Your encouragement and help have been greatly appreciated.

TABLE OF CONTENTS

	PAGE
DECLARATION	i
APPROVAL	ii
DEDICATION	iii
ABSTRACT	1
ABSTRAK	2
ACKNOWLEDGMENTS	3
TABLE OF CONTENTS	4
LIST OF TABLES	6
LIST OF FIGURES	8
LIST OF APPENDICES	12
LIST OF ABBREVIATION	13
LIST OF PUBLICATIONS	14
CHAPTER 1	15
INTRODUCTION	15
1.1 Background	15
1.2 Problem Statement	18
1.3 Research Objectives	19
1.4 Scope of Work	19
1.5 Contribution of the Thesis	20
CHAPTER 2	22
LITERATURE REVIEW	22
2.1 Introduction to Microwave Resonators and Sensing	22
2.2 Microwave Sensors for Material Characterization	23
2.2.1 Overview of the Need for Precise Material Characterization in Industries	23
2.2.2 Classification of Material Characterization Methods	23
2.2.3 The Rise of Microwave Sensors in Material Characterization	29
2.3 Split Ring Resonator (SRR)	30
2.3.1 Working Principle of Split Ring Resonators	31
2.3.2 SRR Equivalent Circuit	32
2.3.3 Applications of SRR in microwave sensing	33
2.3.4 The Effect of SRR Design on Sensor Sensitivity and Performance	34
2.4 Defected Ground Structure DGS	35
2.4.1 Working Principles and Basic Structure	36
2.4.2 Unit Structure	37
2.4.3 Circuit Representation	38
2.4.4 Applications	41
2.5 SRR and DGS for Microwave Application	43
2.6 Recent Advances in Microwave Sensors for Material Characterization	44
2.7 Summary of Literature and Gaps Identified	58
CHAPTER 3	59
RESEARCH METHODOLOGY	59
3.1 Flow Chart of the Project	60

3.2	Design of Microwave Sensor	63
3.2.1	Microstrip	64
3.2.2	Design A (SRR)	66
3.2.3	Design B (SRR DGS)	68
3.2.4	Design C (DGS)	69
3.2.5	Design D (DGS with Slot)	71
3.2.6	Equivalent Circuit	72
3.3	Quality Factor	75
3.4	Polynomial Fitting Method	76
3.5	Sensitivity Analysis	77
3.6	Simulation Process	78
3.6.1	Material Characterization	79
3.7	Fabrication	80
3.8	Measurement and Verification	83
CHAPTER 4		85
MICROWAVE RESONATOR SENSOR		85
4.1	Introduction	85
4.2	Simulation and Measurement of Proposed Sensors	85
4.2.1	Design A	85
4.2.2	Design B	86
4.2.3	Comparison of Design A and B	87
4.2.4	Design C	89
4.2.5	Design D	90
4.2.6	Comparison of Design C and D	91
4.3	Polynomial Equation	92
4.3.1	Design A	93
4.3.2	Design B	94
4.3.3	Design C	95
4.3.4	Design D	97
4.4	Analysis of The Proposed Sensors with Solid Materials	98
4.4.1	Design A	99
4.4.2	Design B	102
4.4.3	Design C	104
4.4.4	Design D	107
4.5	Sensitivity Analysis	114
4.6	Comparison of the Proposed Sensor with Recent Findings	115
CHAPTER 5		118
CONCLUSION AND FUTURE WORK		118
5.1	Conclusion	118
5.2	Future Work	120
REFERENCES		123
APPENDIX A		136
APPENDIX B		138
APPENDIX C		140

LIST OF TABLES

TABLE	TITLE	PAGE
Table 2.1:	Frequency change with various dielectric of solid specimens. SUTs (Al-Gburi et al., 2023)	46
Table 2.2:	Comparison between the single-ring and double- ring CSRR.	49
Table 2.3:	Current trend and development of planar microwave resonators in recent years	56
Table 3.1	Parameter Specifications of design A	67
Table 3.2:	Parameter Specifications of design B	69
Table 3.3:	Parameter Specifications of design C	70
Table 3.4:	Parameter Specifications of design C and D	72
Table 4.1:	Comparison of Design A and B	88
Table 4.2	Comparison of Design C and D	92
Table 4.3:	Simulation verses measurement using polynomial equation of Design A	94
Table 4.4:	Simulation verses measurement using polynomial equation of Design B	95
Table 4.5:	Simulation verses measurement using polynomial equation of Design C	96
Table 4.6:	Simulation verses measurement using polynomial equation of Design D	98
Table 4.7:	Comparison of simulation and measurement with MUT for Design A	101
Table 4.8:	Comparison of simulation and measurement with MUT for Design B	104
Table 4.9:	Comparison of simulation and measurement with MUT for Design C	106
Table 4.10:	Comparison of simulation and measurement with MUT for Design D	109
Table 4.11:	Sensitivity comparison of Design C and D	115



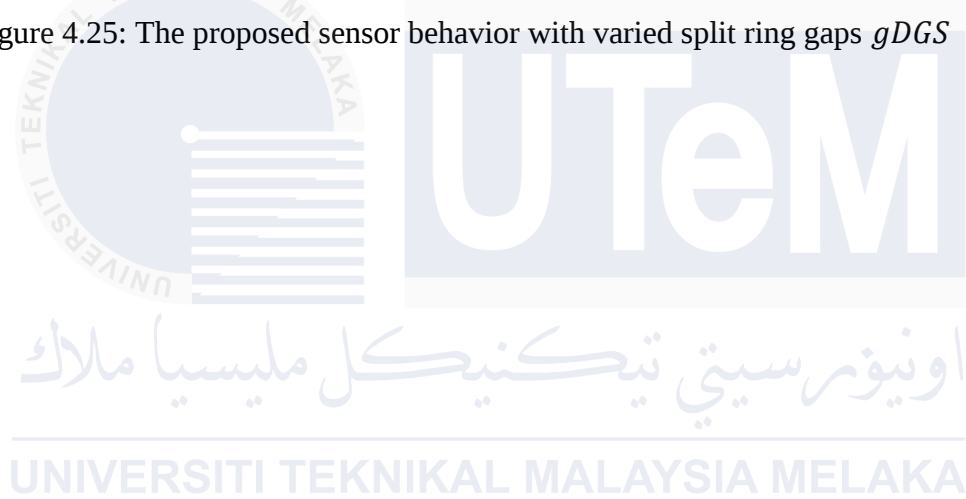
LIST OF FIGURES

FIGURE	TITLE	PAGE
Figure 2.1:	Material Characterization Methods	24
Figure 2.2:	Material characterization using non-resonant method (Chen, Lin-Feng, 2004)	25
Figure 2.3:	Microstrip structure TEM fields	29
Figure 2.4:	SRR trend structures (Alrayes and Hussein, 2021)	31
Figure 2.5:	(a) SRR Equivalent Circuit (b) SRR Equivalent Circuit with microstrip line (Ye, Wang, et al., 2022)	32
Figure 2.6:	DGS trend structures (Bhuiyan and Karmakar, 2014)	36
Figure 2.7:	Various of DGS shapes (Bhuiyan and Karmakar, 2014)	38
Figure 2.8:	RLC equivalent circuits of DGS (Garg and Kaur, 2014)	39
Figure 2.9:	π Shaped equivalent circuits of DGS (Garg and Kaur, 2014)	40
Figure 2.10:	Quasi-static equivalent circuits of DGS (Garg and Kaur, 2014)	41
Figure 2.11:	Fabricated prototype of Curve-feed CSRR sensor; (a) Top and (b) Bottom view (Al-Gburi et al., 2023)	45
Figure 2.12:	The frequency response of the curve-feed CSRR sensor with the presence of solid SUTs (Al-Gburi et al., 2023)	46
Figure 2.13:	S-parameter response of (a) without D-SRR, (b) 2 D-SRRs, (c) 4 vertical D-SRRs, (d) 4 horizontal D-SRRs, (e) 6 horizontal D-SRRs, (f) 8 horizontal D-SRRs (Masrakin et al., 2023)	48

Figure 2.14: Measured S21 of (a) single-ring and (b) double-ring CSRR when unloaded, with container and when loaded with NH3-N (Samsuri et al., 2023)	49
Figure 2.15: (a) is the simulated and measured result and (b) is the fabricated sensor from (Oliveira et al., 2020)	50
Figure 2.16: Photographs of fabricated single and double SRR sensors (Ye, Wang, et al., 2022)	51
Figure 2.17: Measured transmission coefficient of the proposed sensor (Ye, Wang, et al., 2022)	52
Figure 2.18: Prototype of the proposed sensor (Bhushan et al., 2021)	52
Figure 2.19: Simulated and measured S21 of the proposed sensor (Bhushan et al., 2021)	53
Figure 2.20: Layout of DGS-CPW-SRR sensor (Gong et al., 2024)	54
Figure 2.21: Measured and simulated transmission coefficients of the sensor without load versus frequency (Gong et al., 2024)	54
Figure 3.1: Flow chart of the Project	61
Figure 3.2: designs classification	64
Figure 3.3: SRR sensor architecture (a) top and (b) bottom	67
Figure 3.4: SRR DGS sensor architecture (a) top and (b) bottom	68
Figure 3.5: DGS sensor architecture (a) top and (b) bottom	70
Figure 3.6: Design D (DGS with slot) sensor architecture (a) top and (b) bottom	71
Figure 3.7: Equivalent circuit of design A	73
Figure 3.8: Equivalent circuit of Design B	74
Figure 3.9: Equivalent circuit of designs C and D	74
Figure 3.10: Loaded and unloaded frequency	76
Figure 3.11: CST interface with proposed SRR sensor under MUT.	79

Figure 3.12: E-field distribution of (a) SRR and SRR DGS, (b) DGS SRR and (c) DGS SRR with added slot	80
Figure 3.13: Fabrication process	81
Figure 3.14: Flow of fabrication process.	82
Figure 3.15: Top view of fabricated sensors where (a) design A, (b) design B, (c) design C, and (d) design D	82
Figure 3.16: Ground plane of fabricated sensors where (a) design A, (b) design B, (c) design C, and (d) design D	83
Figure 3.17: Measurements setup	84
Figure 4.1: Simulation verses measurement of Design A	86
Figure 4.2: Simulation verses measurement of Design B	87
Figure 4.3: Simulation verses measurement of Design C	90
Figure 4.4: Simulation verses measurement of Design D	91
Figure 4.5: Polynomial curve fitting of Design A	94
Figure 4.6: Polynomial curve fitting of Design B	95
Figure 4.7: Polynomial curve fitting of Design C	96
Figure 4.8: Polynomial curve fitting of Design D	97
Figure 4.9: E-field distribution for all designs	99
Figure 4.10: Simulation results of frequency response with MUT of design A	100
Figure 4.11: Measurement results of frequency response with MUT of design A	101
Figure 4.12: Simulation verses measurement Design A	101
Figure 4.13: Simulation results of frequency response with MUT of design B	103
Figure 4.14: Measurement results of frequency response with MUT of design B	103
Figure 4.15: Simulation verses measurement Design B	104
Figure 4.16: Simulation results of frequency response with MUT of design C	105

Figure 4.17: Measurement results of frequency response with MUT of design C	106
Figure 4.18: Simulation verses measurement Design C	106
Figure 4.19: Simulation results of frequency response with MUT of design D	108
Figure 4.20: Measurement results of frequency response with MUT of design D	108
Figure 4.21: Simulation verses measurement Design D	109
Figure 4.22: The proposed sensor behavior with varied lengths L	111
Figure 4.23: The proposed sensor behavior with varied widths W	112
Figure 4.24: The proposed sensor behavior with varied internal widths IW	113
Figure 4.25: The proposed sensor behavior with varied split ring gaps $gDGS$	114



LIST OF APPENDICES

APPENDIX	TITLE	PAGE
A	Data Sheet Roger RT/Duroid 5880	136
B	Data Sheet Roger RT/Duroid 4350	138
C	Data Sheet FR-4	140



اونيورسيتي تېكنيكل مليسيا ملاك

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

LIST OF ABBREVIATION

SRR	-	Split Ring Resonator
DGS	-	Defected Ground Structure
CSRR	-	Complementary Split Ring Resonator
CST	-	Computer Simulation Technology
MUT	-	Material Under Test
EM	-	Electromagnetic
VNA	-	Vector Network Analyzer

LIST OF PUBLICATIONS

Journal Articles

“High Responsive Microwave Resonator Sensor for Material Characterization”,
International Journal of Academic Research in Business and Social Sciences,
October 2024



CHAPTER 1

INTRODUCTION

This chapter provides an introductory background to the area of the microwave resonators and discusses the characteristics that make them attractive choices in designing new or improved electromagnetic devices for material characterization applications. It also explains the objectives and motivations behind the presented research. Furthermore, the original contributions in this thesis are highlighted followed by the structure organization of the thesis.

1.1 Background

The advancement of microwave industrial technology, particularly in material characterization applications has expanded the capabilities of microwave sensors. These sensors are now widely used in industries such as food quality assessment, pharmaceutical analysis, and non-destructive testing, enabling precise measurement of material properties such as permittivity and permeability. Microwaves are electromagnetic waves with wavelengths ranging from one centimetre to one meter. The wavelengths correspond to frequencies ranging from 300 MHz (1 m wavelength) to 30 GHz (1 cm wavelength). This band encompasses the ultrahigh-frequency (UHF) and superhigh-frequency (SHF) spectrums (Clarricoats, 1967). These frequencies are commonly utilized by radiosondes, surveillance radars, airborne radars, navigational aids, common-carrier land mobile communications, radar astronomy, Bluetooth, and radio frequency identification (RFID) (Nicolaescu and Oroian, 2001; Khan, Duan and Sherbaz, 2012).

All of these applications have utilized microwave materials. Contemporary research domains in materials science, solid-state physics, and electrical and electronic engineering concentrate on the advancement of these materials and the analysis of their properties at microwave frequencies. Comprehensive understanding of the properties of materials operating at microwave frequencies is essential for the development of high-frequency circuits (Waser, 2005). The characterization of material properties is a critical subject in microwave electronics for numerous companies and researchers (Chen, Lin-Feng, 2004). Electromagnetic characterization entails a thorough comprehension of a material's electromagnetic parameters (complex permittivity and permeability) as functions of frequency.

In addition to the theoretical comprehension of electromagnetic properties at these frequencies (Reddy and Raghavan, 2013), accurate constitutive properties are essential in microwave engineering. Material property characterization at microwave frequencies has been developed and utilized since the early 1950s (Falcone, 2017). Since World War II, the design and fabrication of radar absorption materials have depended significantly on the ability to tailor the properties of composite materials (Nicolaescu and Oroian, 2001). Significant advancements have been made in recent decades, resulting in the development of various methodologies and procedures. Precise understanding of material properties, including permittivity and permeability, is essential for the fabrication of electronic circuits. The advancement of technology and the investigation of electromagnetic materials benefit bioengineering, agriculture, food processing, and healthcare practices, as well as monitoring manufacturing processes and conducting nondestructive evaluations of both samples and products (Przemysław Sobkiewicz, 2021).

Dielectric, waveguide, and coaxial probe structures represent merely a subset of the diverse topological methodologies commonly employed for the extraction of material

properties. These methods enable highly accurate measurements at a singular or specific set of frequencies (Alhegazi et al., 2018). Nonetheless, these conventional methods are often bulky, costly to produce, and require a substantial quantity of samples for the measurement process (Alhegazi et al., 2019). Planar resonant techniques have garnered significant attention in recent years owing to their advantages, such as compact size, cost-effectiveness, ease of implementation, and minimal sample requirements. Conversely, these methods exhibit a low Q-factor and inadequate sensitivity, thereby constraining their applicability and the range of materials (Alahnomi et al., 2019; Alhegazi et al., 2019).

Consequently, the dielectric properties of materials will be assessed utilizing a distinctive configuration of planar microwave sensors founded on a defected ground structure split ring resonator, enabling real-time measurement of solid materials through a single-port sensor. The proposed sensor utilizes perturbation theory, whereby the resonant frequencies and quality factors are influenced by the dielectric properties of the examined solid materials. This research will develop a sensing method operating at a frequency of 2.5 GHz within the range of 1.5 GHz to 3 GHz. It necessitates the analysis of simulation and test data concerning the sensor's sensitivity relative to the resonant frequency, quality factor, and frequency bandwidth. The outcome is anticipated to yield a superior Q-factor relative to the current literature. This research is crucial for characterizing and ascertaining material properties in biosensing and applications within the food and beverage industry.

1.2 Problem Statement

In recent times, there has been a growing interest in the research of microwave resonator sensors. This is because they are highly sought-after instruments for detecting and providing valuable information on unknown material properties. Accurate measurements from these devices are crucial in meeting industrial requirements for producing safe products that are fit for human consumption (Kiani, Rezaei and Navaei, 2020; Z. Li et al., 2022a). Additionally, they enable initial evaluations in investigating content and enhancing the diversity of methods for determining substance compositions in modern materials. Ensuring the reliability of microwave resonator sensors is a critical concern in implementing material characterization (Gan et al., 2020). The research on the non-planar resonator sensor is a key focus of many researchers as it is the most accurate measurement. For example, the following microwave sensors were used for characterizing the dielectric properties of materials. Julrat and Trabelsi used free space (Julrat and Trabelsi, 2019), where waveguide is used by Wang et al and Mohammadi et al (Wang et al., 2019; Mohammadi et al., 2020). These sensors offer the advantages of measurements in a broad range of samples, and they exhibit minimum error tolerance for material characterization due to their abilities in characterizing materials over a high Q factor.

One of the challenges facing non-planar resonator sensors is the complexity of conventional characterization techniques for the structure. Although these sensors are accessible, their large size limits their usefulness in several important applications (Alahnomi et al., 2021). As a result, planar resonator sensors have gained significant interest in recent years due to their simple design, easy manufacturing process, and compact size. However, a poor unloaded Q-factor and electric fields (E-fields) restricts the range of materials that can be used and controlled. According to Ebrahimi, Scott and Ghorbani, the proposed sensor is capable of determining the dielectric properties for different types of

samples like solid, semi-solid, and liquid properties of the material under test (MUT) under a single resonator compared to most sensors focusing only on a single MUT (Ebrahimi, Scott and Ghorbani, 2020). Moreover, a high-sensitivity microwave sensor was proposed to retrieve the complex permittivity of solid sample. The researchers have implemented the defected ground structure (DGS) in order to increase the Q-factor, sensitivity and notch depth of traditional SRR-based sensors (Ye, Wang, et al., 2022)(Ye, Zhao, et al., 2022). However, the current challenges in DGS and SRR include fabrication complexity, sensitivity to environmental factors, and trade-offs between miniaturization and performance. Achieving high-Q factors while maintaining compactness remains difficult.

1.3 Research Objectives

The overall aim of this research project is to develop a new high Q-factor sensor for detecting the material properties while benefiting small size. To be more specific, the following list shows the objectives of this project:

- i. To design two different types of high Q-factor planar microwave sensor which are SRR with DGS and DGS SRR resonate at 2.0 to 2.5 GHz for solid characterization.
- ii. To analyze microwave sensor's simulation and measurement results based on the return loss, quality factor, resonant frequency shift, and electric field distribution.
- iii. To characterize and evaluate the properties of the solid materials in the laboratory using the proposed high Q-factor planar microwave sensors.

1.4 Scope of Work

The scope of the project is listed below:

- i. Develop a planar microwave resonator sensor based on the microstrip SRR with DGS and DGS SRR structure using CST studio suite.