PLANAR MICROWAVE SENSOR WITH HIGH SENSITIVITY FOR MATERIAL CHARACTERIZATION BASED ON SQUARE SPLIT RING RESONATOR

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MASTER OF SCIENCE IN ELECTRONIC ENGINEERING

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Faculty of Electronics and Computer Engineering

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

I declare that this thesis entitled “Planar Microwave Sensor with High Sensitivity For Material Characterization Based On Square Split Ring Resonator” 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 : Harry Sucitra Binti Roslan

Date : February 2023

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	:	February 2023

DEDICATION

Thank and worship Allah the Almighty, my Creator, and Sustainer, for all that I have received from the beginning of my existence.

This study is devoted to my dear parents, En Roslan Bin Idrus and Pn Yetti Binti Zakir who have been a continual source of support and motivation for me.

They have given me the motivation and self-control to approach work with passion and dedication.

This endeavor would not have been feasible without their love and support.

ABSTRACT

Microwave sensors for material characterization are the most widely used sensors in the food sector, quality control, biomedical, and industrial applications. One of the prospective methods for very precise dielectric material characterization measurements at a single or discrete frequency is the microwave resonant approach. Historically, waveguide, dielectric, and coaxial resonators have been used to characterize materials because they offer great sensitivity and precision. However, resonator sensors are typically large, expensive to produce, and require a large amount of material to detect the prior sample of the material being tested. Therefore, because of their benefits of being small in size, inexpensive, and simple to manufacture, planar resonant methods have become the most preferred approach in recent years. However, the poor sensitivity and low Q-factor value of this method limit the applicability for material characterization. Thus, this thesis introduces a single-band metamaterial to overcome the weakness of this technique by using the perturbation method in which the dielectric properties of the resonator affect the Q-factor and resonance frequency. This proposed sensor operated at 2.5 GHz in the range of 1 GHz to 4 GHz for material characterization of solid and liquid samples. These sensors were constructed using RT/Duroid Roger 5880 as a substrate with a dielectric constant of 2.2, loss tangent of 0.0009, and copper thickness of 17.5 µm. The integrated microfluidic sensing case is designed using Epoxy Resin. The epoxy resin has better corrosion resistance and is less influenced by heat and water than other polymeric matrices. The liquid sample will be injected into these microfluidic cases that will be placed at the maximum concentration of E-flux at the top of the copper structure. E-flux areas with high concentrations are more susceptible to dielectric changes. The proposed sensor requires the same size of the solid sample with a different thickness of the sample and the same amount of liquid sample to be tested which is 0.3 ml at a time. The sensor is designed by using computer simulation technology (CST) software and analyzed using a vector network analyzer (VNA). The design of the structure resonator is based on the mathematical equation and optimization of the parameter value. As a result, this square split ring resonator (SSRR) sensor generates narrow resonance, minimal insertion loss, and a high Q-factor value of 430 at 2.5 GHz. Consequently, the SSRR sensor's sensitivity is 98.59 % accuracy which is higher than those of previous studies. In conclusion, this sensor design is successfully demonstrated in terms of theoretical, simulation, and validation through experimental works. Due to this, it is proven that this sensor is suitable for material characterization that required a small number of samples to be tested which will be needed in many applications. This evidence supports the suggested sensor's use as a tool for material characterization, particularly when identifying material characteristics.

PENDERIA GELOMBANG MIKRO SATAH DENGAN KEPEKAAN TINGGI UNTUK PENCIRIAN BAHAN BERASASKAN PENYALUN GELANG BELAH SEGIEMPAT SAMA

ABSTRAK

Penderia gelombang mikro untuk pencirian bahan ialah penderia yang paling banyak digunakan dalam sektor makanan, kawalan kualiti, aplikasi bioperubatan dan industri. Salah satu kaedah prospektif untuk ukuran pencirian bahan dielektrik yang sangat tepat pada frekuensi tunggal atau diskret ialah pendekatan resonan gelombang mikro. Dari segi sejarah, pandu gelombang, dielektrik dan resonator sepaksi telah digunakan untuk mencirikan bahan kerana ia menawarkan kepekaan dan ketepatan yang hebat. Walau bagaimanapun, penderia resonator biasanya besar, mahal untuk dihasilkan dan memerlukan sejumlah besar bahan untuk mengesan sampel bahan yang diuji sebelumnya. Oleh itu, kerana faedahnya bersaiz kecil, murah, dan mudah untuk dikeluarkan, kaedah resonan satah telah menjadi pendekatan yang paling digemari sejak beberapa tahun kebelakangan ini. Walau bagaimanapun, sensitiviti yang lemah dan nilai faktor Q yang rendah bagi kaedah ini mengehadkan kebolehgunaan untuk pencirian bahan. Justeru, tesis ini memperkenalkan metamaterial jalur tunggal untuk mengatasi kelemahan teknik ini dengan menggunakan kaedah perturbasi di mana sifat dielektrik resonator mempengaruhi faktor Q dan frekuensi resonan. Sensor yang dicadangkan ini beroperasi pada 2.5 GHz dalam julat 1 GHz hingga 4 GHz untuk pencirian bahan bagi sampel pepejal dan cecair. Penderia ini telah dibina menggunakan RT/Duroid Roger 5880 sebagai substrat dengan pemalar dielektrik 2.2, tangen kehilangan 0.0009 dan ketebalan kuprum 17.5 µm. Sarung penderiaan mikrobendalir bersepadu direka bentuk dengan menggunakan Resin Epoksi. Resin epoksi mempunyai rintangan kakisan yang lebih baik dan kurang dipengaruhi oleh haba dan air daripada matriks polimer lain. Sampel cecair akan disuntik ke dalam bekas mikrobendalir ini yang akan diletakkan pada kepekatan maksimum E-fluks di bahagian atas struktur kuprum. Kawasan e-fluks dengan kepekatan tinggi lebih terdedah kepada perubahan dielektrik. Penderia yang dicadangkan memerlukan saiz sampel pepejal yang sama dengan ketebalan sampel yang berbeza dan jumlah sampel cecair yang sama untuk diuji iaitu 0.3 ml pada satu masa. Penderia direka bentuk dengan menggunakan perisian teknologi simulasi komputer (CST) dan menganalisis menggunakan penganalisis rangkaian vektor (VNA). Reka bentuk resonator struktur berdasarkan persamaan matematik dan pengoptimuman nilai parameter. Akibatnya, penderia resonator cincin belah empat segi (SSRR) ini menjana resonans sempit, kehilangan sisipan minimum dan nilai faktor Q tinggi sebanyak 430 pada 2.5 GHz. Akibatnya, kepekaan sensor SSRR adalah 98.59 % ketepatan yang lebih tinggi daripada kajian terdahulu. Bukti ini menyokong penggunaan penderia yang dicadangkan sebagai alat untuk pencirian bahan, terutamanya apabila mengenal pasti ciri bahan. Sebagai kesimpulan, reka bentuk sensor ini berjaya ditunjukkan dari segi teori, simulasi dan pengesahan melalui kerja-kerja eksperimen. Disebabkan ini, terbukti bahawa sensor ini sesuai untuk pencirian bahan yang memerlukan sebilangan kecil sampel untuk diuji yang akan diperlukan dalam pelbagai aplikasi. Bukti ini menyokong penggunaan sensor yang dicadangkan sebagai alat untuk pencirian bahan, terutamanya apabila mengenal pasti ciri-ciri bahan.

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LIST OF ABBREVIATIONS

UHF	-	Ultrahigh Frequency
SHF	-	Superhigh Frequecy
RFID	-	Radio Frequency Identification
E-FIELD	-	Electric Field
PM	-	Perturbation Method
TE	-	Transverse Electrical
TM	-	Transverse Magnetic
AC	-	Alternating Current
CPW	-	Coplanar Waveguide
CFA	-	Complementary Folded Arm
DS-CSRR	-	Double Slit Complementary Split Ring Resonator
SSRR	-	Square Split Ring Resonator
SRR	-	Split Ring Resonator
Q-Factor	-	Quality Factor
PEC	-	Perfect Electric Conductor
EM	-	Electromagnetic
DXF	-	Drawing Exchange Format
UV	-	Ultraviolet
CST	-	Computer Simulation Technology
VNA	-	Vector Network Analyzer
DUT	-	Device Under Test
LUT	-	Liquid Under Test
SUT	-	Solid Under Test
MUT	-	Material Under Test

LIST OF SYMBOLS

μm	-	Micrometre
mm	-	Millimetre
ε_r	-	Permittivity
$\varepsilon_r{}'$	-	Real Permittivity
$\varepsilon_r{}''$	-	Imaginary Permittivity
ε_o	-	Permittivity of Free Space
G	-	Gain
L	-	Inductor
C	-	Capacitor
R	-	Resistor
E	-	Electric Fields
Z_0	-	Characteristic Impedance
ε_{eff}	-	Effective Dielectric Constant
w	-	Width
l	-	Length
h	-	Height (thickness)
g	-	Gap Width
c	-	Speed of Light
L	-	Actual Length of Patch
L_{eff}	-	Effective Length
ΔL	-	Incremental Length of Patch
f_r	-	Resonant Frequency
f_o	-	Center Frequency
f_c	-	Frequency without Sample
f_s	-	Frequency with Sample
Δf	-	Frequency Shifting
f_1	-	Lowest Frequency
f_2	-	Upper Frequency
Q	-	Quality Factor

Q_{MUT}	-	Quality Factor of Material Under Test
Q_U	-	Unloaded Quality Factor
BW	-	Bandwidth
dB	-	Decibels
S_{11}	-	Return Loss
S_{21}	-	Insertion Loss

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LIST OF PUBLICATIONS

List of Journal

Harry, S. R., Zakaria, Z., Said, M. A. M., Alahnomi, R. and Misran, M. H., 2021. ‘Design of Dual Band Meta-Material Resonator Sensor for Material Characterization’, *Applied Computational Electromagnetics Society Journal*, 36(4), pp. 473–478. doi: 10.47037/2020.ACES.J.360414. (Published)

Roslan, H. S., Said, M. A. M., Zakaria, Z. and Misran, M. H., 2022. ‘Recent development of planar microwave sensor for material characterization of solid , liquid , and powder : a review’, *Bulletin of Electrical Engineering and Informatics*, 11(4). doi: 10.11591/eei.v11i4.4120. (Published)

List of Exhibitions

Ekspo Rekacipta & Pameran Penyelidikan, ereka 2021 - (Gold Medal)

The 11th Creation, Innovation, Technology and Research Exposition CITREX 2021 UMP - (Gold Medal)

Malaysia Leading Internasional Innovation & Technology Event, Malaysia Technology Expo MTE 2022 – (Gold Medal)

CHAPTER 1

INTRODUCTION

1.1 Research Background

The growth of microwave industrial technology, particularly in applications for material characterization, has led to a revolution in the field of microwave sensors. Microwaves are electromagnetic waves having wavelengths between one centimeter and one meter. These wavelengths correspond to frequencies between 300 MHz (1 m wavelength) and 30 GHz (1 cm wavelength). The spectrums of ultrahigh-frequency (UHF) and superhigh frequency (SHF) are covered by this band (Clarricoats, 1967). These frequencies are frequently employed 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 made use of microwave materials. Current research areas in materials science, solid-state physics, and electrical and electronic engineering focus on the development of these materials and the examination of their characteristics at microwave frequencies. In-depth knowledge of the characteristics of materials that function at microwave frequencies is required for the construction of high-frequency circuits. (Waser, 2005). Because of this, the characterization of material characteristics is a crucial topic in microwave electronics for many companies and researchers (Chen et al., 2004). Electromagnetic characterization is the comprehensive understanding of a material's electromagnetic parameters (complex permittivity and permeability) as functions of frequency.

Aside from the academic understanding of electromagnetic properties at these frequencies (von Hippel and Morgan, 1955; Woolley, 1957; Reddy and Raghava, 2013; Falcone, 2017), precise constitutive properties are required in microwave engineering (Ramo, Whinnery and Duzer, 1994). Since the early 1950s, material property characterization at microwave frequencies has been developed and used. Designing and creating radar absorption materials since World War II has relied heavily on the capacity to customize the characteristics of composite materials (Nicolaescu and Oroian, 2001). Massive advancements have been achieved over the past several decades, and a variety of methodologies and procedures have been created. Accurate knowledge of material properties such as permittivity and permeability is required for the construction of electronic circuits. Technology development and the research of electromagnetic materials are helpful for bioengineering, agriculture, food processing, and healthcare procedures (Stuchly and Stuchly, 1983), also in overseeing the manufacturing process and evaluating nondestructively both samples and goods (Sobkiewicz, Bienkowski and Blazejewski, 2021).

The dielectric, waveguide and coaxial probe structures are only a few examples of the various types of topological approaches that are typically given as useful tools for extracting material attributes. These methods have the possibility for very precise measurements at a single or discrete set of frequencies (Alahnomi et al., 2016). However, these traditional methods are frequently large, expensive to fabricate, and need a significant volume of samples for the measurement procedure (Alhegazi et al., 2019). Planar resonant techniques have therefore attracted a lot of attention in recent years due to their benefits, including their small size, low cost, simplicity of implementation, and need for only a small quantity of samples. On the other hand, these methods have weak Q-factor and poor sensitivity, which limit their applicability and the spectrum of materials (Alahnomi et al., 2019; Alhegazi et al., 2019).

For this reason, dielectric characteristics of materials will be determined and detected using a unique construction of planar microwave sensors based on a Square Split Ring Resonator (SSRR) with the capability of real-time measurement for both solid and liquid specimens in a single port network sensor. The suggested sensor is based on employing the perturbation theory where frequency resonants and quality factors are affected by dielectric materials of tested solid