DESIGN OF MICROWAVE RESONATOR SENSOR FOR MATERIAL CHARACTERIZATION

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PROJEK SARJANA MUDA II

Tajuk Projek : **Design of Microwave Resonant Sensor for Material Characterization**

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ABSTRACT

In the last few years, several designs of the microwave resonator, which has satisfied various objectives, have been proposed for materials characterization. Special attention is devoted to resonance techniques that are more accurate and sensitive compared to the transmission-reflection methods. Material characterization using Microwave resonant sensor is considered one of the most accurate way to obtain material properties. Resonant method usually has higher accuracy and sensitivity than other methods, and it is convenient for low loss materials. A review of dielectric material properties and currently available measurement methods is included. Enhanced coupling ring resonant with 1.2 GHz microstrip design is presented for the measurement of thin and low-loss materials such as FR4, Roger 4350 and Roger 5880. This design is based on electromagnetic simulation in terms of resonant frequency, quality factor and permittivity. Design, simulation, fabrication and measurement process are illustrated in this study. Comparison between simulation and measurement results is shown in this study. In this paper, enhanced coupling ring resonator sensor is proposed as a suitable component for performance enhancement of microwave sensors. This sensor has been employed for enhancing the insertion loss of the microwave sensors. Using the same device area, we can achieve a high Q-factor of 209.11 from the periphery enhancement using enhanced coupling ring. Resonant frequency at 1st, 2nd, 3rd, and 4th harmonics have been completely suppressed well above -20 dB rejection level without visible changes in the passband filter characteristics. The most significant of using enhanced coupling ring is to be used for various industrial applications such as food industry, quality control, bio-sensing medicine and pharmacy. It also provides useful information to improve the design, processing, quality and control of product. The simulation result that device is a viable candidate for the performance enhancement of microwave sensors has been verified.

ABSTRAK

Dalam beberapa tahun kebelakangan ini, beberapa reka bentuk resonator gelombang mikro, yang telah memenuhi pelbagai objektif, telah dicadangkan untuk bahan-bahan pencirian. Perhatian khas ditumpukan kepada resonans teknik-teknik yang lebih tepat dan sensitif berbanding kaedah penghantaran-renungan. pencirian bahan menggunakan Microwave sensor salunan dianggap sebagai salah satu cara yang paling tepat untuk mendapatkan sifat bahan. kaedah salunan biasanya mempunyai ketepatan yang tinggi dan sensitiviti berbanding kaedah lain, dan ia adalah mudah untuk bahan-bahan kehilangan rendah. Kajian semula sifat bahan dielektrik dan kaedah penilaian sedia ada disertakan. cincin gandingan dipertingkatkan salunan dengan reka bentuk mikrostrip 1.2 GHz dikemukakan untuk pengukuran bahan nipis dan rendah-kerugian seperti FR4, Roger 4350 dan Roger 5880. Reka bentuk ini adalah berdasarkan kepada simulasi elektromagnet dari segi kekerapan salunan, faktor kualiti dan ketelusan. Design, simulasi, fabrikasi dan proses pengukuran digambarkan dalam kajian ini. Perbandingan antara keputusan simulasi dan pengukuran ditunjukkan dalam kajian ini. Dalam kertas ini, dipertingkatkan gandingan sensor cincin resonator adalah dicadangkan sebagai komponen sesuai untuk peningkatan prestasi sensor gelombang mikro. sensor ini telah digunakan untuk meningkatkan kehilangan sisipan sensor gelombang mikro. Menggunakan kawasan peranti yang sama, kita boleh mencapai Q-faktor yang tinggi 209,11 dari peningkatan pinggir menggunakan cincin gandingan dipertingkatkan. kekerapan salunan pada 1, 2, 3, dan harmonik ke-4 telah sepenuhnya ditindas jauh melebihi -20 dB tahap penolakan tanpa perubahan ketara dalam ciri-ciri penapis passband. Yang paling penting menggunakan cincin gandingan dipertingkatkan adalah untuk digunakan bagi pelbagai aplikasi industri seperti industri makanan, kawalan kualiti, perubatan bio-penderiaan dan farmasi. Ia juga menyediakan maklumat yang berguna untuk memperbaiki reka bentuk, pemprosesan, kualiti dan kawalan produk. simulasi menyebabkan peranti yang adalah calon yang berdaya maju untuk meningkatkan prestasi sensor microwave telah disahkan.

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TABLE OF CONTENTS

CHAPTER I

INTRODUCTION

This chapter explains the overview of this project which includes the information of the list below:

1. Introduction to the project
2. Objective
3. Problem statement
4. Scope of project
5. A Brief Description of the thesis
6. Expected Outcome

1.1 Project Background

This project is about the device that can identify and characterize some kind of material at frequency 1.2GHz. This sensor is suitable for various industry applications such as food industry/ halal-hub, quality control, medicine & pharmaceutical. It is believed that this technique would lead for a promising solution of characterizing material particularly in determining material properties and quality by using the micsrostrip ring resonator technique on FR4 substrate.

Microwave resonators offer the potential for highly accurate measurements with high sensitivity of the materials characterization at single or discrete set of frequencies.

These resonators are suitable for various industry applications such as:

- Food processing
- Agriculture
- Dairy product
- Bio – engineering
- Geo-science

Dielectric constant of any material is an important parameter to be considered for numerous applications [1]-[2] in various fields. For this different kind of microwave sensors are deployed to study the electromagnetic radiation of microwave region. Microwave dielectric measurement methods are of two types, namely resonant and non-resonant methods. Where resonant method have relatively higher accuracy than the non-resonant ones.

In resonant methods, the material under test is introduced to a resonator thus altering the electromagnetic boundaries of the resonator, and the electromagnetic properties of the sample are deduced from the change of the resonant properties of the resonator. Due to its high accuracy and its flexibility in sample preparation, the resonant method is widely used for low-loss samples, powders, small size samples and samples of irregular shapes. Different applications require different sensors and they are developed for particular applications. Figure 1.1 shows a typical behaviour of permittivity as a function of frequency. The permittivity of material is related to a variety of physical phenomena, ionic conduction, dipolar relaxation, atomic polarization and electronic polarization are the main mechanisms that contribute to the permittivity of dielectric material.

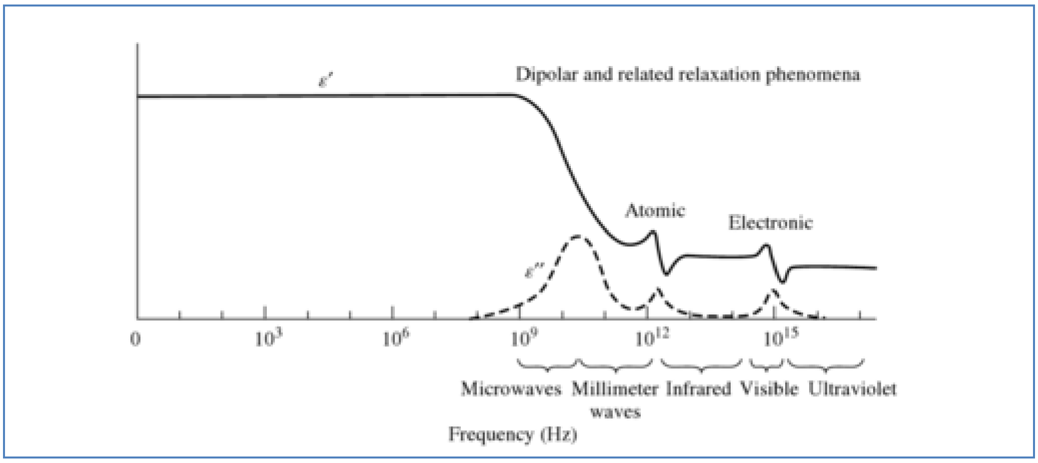

Figure 1.1: Frequency dependence of permittivity for hypothetical dielectric

The split ring is a basic geometry for the design of sub-wavelength magnetic Meta material resonators. At microwave frequencies, double split rings design has gained so much popularity. From intuition [3], analytical expressions for resonant frequencies of double ring constitution were derived while the ones with more rigors were confirmed by experiment [3, 4]. The resonant properties of single rings have gathered little study, analytically. Here, an analytical expression for the resonant frequency of the singly split single ring resonator is derived. The geometry used for this analysis is shown in Figure.1.2. The parameters are: the inner radius of the ring, R, the thickness, w, the height, h, and the gap width, g the sub-wavelength split ring resonator can be characterized by the inductance, L, and the capacitance, C.

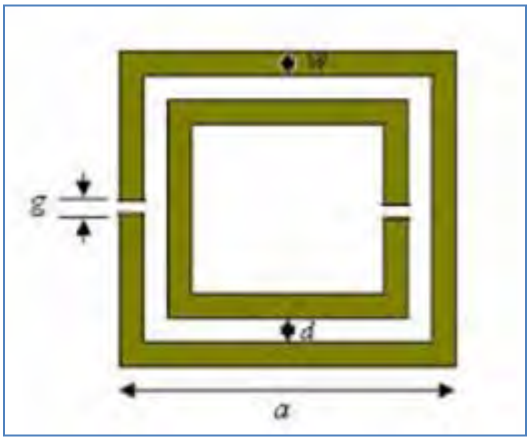

Figure 1.2 Geometries of the ring under analysis.

The SRRs are used to overcome the problem of signal propagation in the narrow band near the resonance frequency. This is done by the magnetic excitation on the ring. On the basis of the SRRs method, many scientists have now introduced other methods for narrow band. Through this method negative permeability can be generated by inductor and capacitor

This project is Design of Microwave Resonator Based Sensor for Material Characterization is to overcome healthy problem, it is necessary to provide a device that can identify and characterize some kind of food we eat every day such as chicken, beef, and fish. This device will make it easy for people to choose suitable food for their healthy and check the validity of food. Besides, it very useful since it is engaged in various system and applications. Material characterization provides useful information to improve design, processing, quality and control of product. There are some method that use to complete this project are design Micro-Strip Ring Resonant, do the simulation, fabrication and measurement from simulation and comparison between simulation results and measurement results should be taken in this project.

1.2 Problem Statement

Various resonators such as coaxial cavity, dielectric, and waveguide resonators have been used for material characterization. However, these types of resonators are often:

- Large in size
- Expensive to build
- Have low sensitivity with poor Q-factor

Thus, planar resonant techniques have gained a considerable interest over the past years due to its advantages such as:

- Low cost
- Ease to manufacture
- Compact size
- High accurate measurements with high sensitivity of the materials characterization

But, planar technique suffers from low sensitivity and poor Q-factors which restrict its use in many important applications and limit the range of materials. To overcome this problem, a new structure of planar microwave sensor for determining and detecting the dielectric properties in common solids is presented to produce higher Q-factor with capability to suppress the undesired harmonic spurious. The presented sensor is based on symmetrical split ring resonator (SSRR) metamaterial structure by employing the perturbation theory, in which the dielectric properties of the resonator affects the Q-factor and resonance frequency of the microwave resonator.

1.3 Objectives

The main objectives for this project are:

1. To characterize material properties through Microwave Resonator Sensor
2. To analyse the material properties through electromagnetic simulation in the terms of permittivity, frequency and quality factor.
3. To validate the simulated result through experimental setup and evaluation in laboratory.

1.4 Scope

The main purpose of this project is to develop a device that can identify material through electromagnetic simulation in terms of resonant frequency, quality factor, and permittivity. This device is limited to measure thin and low-less materials only such as FR4, Roger 4350, and Roger 5880. In this study current methods that use to identify the material properties are considered. Design of a microstrip ring resonant (MMR) at 1.2 GHz, simulation using computer simulation technology (cst) software, fabrication in laboratory using FR-4 material and measurement using Vector Network Analyzer (VNA) are going to be performed in this study. Comparison between simulation results and measurement results should be taken in this project.

1.5 A Brief Description of the thesis

Methodology is actually the general guide to execution of the project. It includes some analysis of the rules or the principles that might include in the project and study of potential methods that will be used in the project. It gives a plan to the one who is going to do the project where it will show planning activities.

First of all, this thesis consist of five chapters which are categorized as introduction, literature review, methodology, results and discussions, and last but not list conclusion and recommendation.

For the first chapter, introduction part discuss about the introduces of project and explains the aim of this project, present the problem formulation through as detail as information about Design of Microwave Resonator Based Sensor for Material Characterization will be discussed.

For the second chapter, literature review part provides a detailed background of the material characterization and methods used to identify the properties. It also provides the techniques and explained more about advantages and disadvantages of projects.

Methodology part for the chapter three and discuss more about the methods and the procedures that used to design the project in detail such as flow chart, specifications, discussions and processing technique.

For chapter four, discuss about the result and discussion. Illustrates and analyses the result of project and discusses the further improvement of device. The last part for chapter five is conclusion and recommendation of this project. Present the conclusion of the strengths and limitation of the project and recommendation for the future works will provided.

CHAPTER II

LITERATURE REVIEW

2.1 Introduction

This chapter focused on the literature review of a component and device in this project. The information, characteristic, operations, advantages and disadvantages of the component and device will be discussed on this chapter. Several technique were developed to characterization the dielectric properties of the materials. There have the researchers are working on the characterization of dielectric material by using difference resonance and transmission/ reflection technique such as cavity perturbation, parallel plate capacitor, microstrip line and split ring resonator techniques.

M.S. Kheir, H.F Hammad, and A.S Omar designed a ring resonator with a rectangular waveguide cavity for estimating the dielectric constant of liquids. By measuring the resonance frequency of the hybrid resonator they calculated the dielectric constant. The material was placed in a very compact area, and the response was measured in the frequency range of 500MHz to 3 GHz [5].

B. Jackson, T.Jayanthy discussed a microstrip loop resonator sensor designed to determine the dielectric constant of a liquid. A dielectric material is placed above microstrip ring resonator and resonator sensor designed for 1GHz for different structure [6].

A.Kumar, S.Sharma and G.Singh proposed a new technique to characterize the homogeneous dielectric materials using rectangular shaped perturb cavity. In this method the samples were placed in the cylindrical form at the center of the cavity. The real and imaginary parts of material‟s permittivity were calculated using the shift in the resonance frequency [7].

Luiene S. Denenicis et al. also proposed a coplanar waveguide linear resonator technique for the characterization of dielectric properties of thin films at room temperature. They deposited thin films of unknown dielectric constant on the resonator using photolithography and measured the response of „s‟ parameters [8].

R .Mustafa developed the measure of dielectric constant of material using ring resonant with single gap and measurement done by measuring the resonant frequency of the ring without the MUT (Material under Test); then by putting the MUT in the gap of the ring and re-measured the resonant frequency between 0.5GHz and 2,5GHz.[9]

Jabita, A.A discussed the microwave micro fluidic sensor is proposed to detect and determine the dielectric properties of common liquids. A microstrip split ring resonator with two gap is adopted for design of the sensor. At 3GHz, very good agreement is demonstrated between simulated and measured results [10].

Rammah, A.A., Zakaria, Z., Ruslan, E., Isa, A.A.M. Material characterization has an application in various areas such as bio-sensing, quality control in the food industry, substrate properties and so on. Many methods have been proposed and used material characterization. These methods can be categorized as near filed sensors, transmission line, free-space methods, and resonant cavity [11].

Many methods have been proposed and used material characterization. These methods can be categorized as nearfiled sensors, transmission line, free-space methods, and resonant cavity [12]. Even though the microwave sensors are deployed for dielectric measurements for materials characterization, they are also used for measuring chemical reactions, humidity, and paramagnetic impurities.

Muhammad Taha Jilani, Wong Peng Wen, Mohammad Azman Zakariya, Lee Yen Cheong. There are also some design modifications to increase the coupling strength. Some of these coupling schemes found in literature are used to reduce the losses and increase the coupling strength. the scheme is known as *loose coupling*. In this method, since the coupling strength is not much higher, its effect on resonance frequency is minimal. But the insertion loss is much higher, however, by selecting optimum gap size it can be reduced [13].

Yanbing Ma, Huaiwu Zhang, Yuanxun Li, Yicheng Wang, Weien Lai. The main advantages of the microwave resonators used as sensors are: high precision level, high Q-factor, easy to design and fabricate, safe to use, reliable, low-cost, high measurement performance and sensitivity, and operating at various distinguished microwave frequencies [14]. Due to the permittivity that depends on the volumetric moisture content in any dielectric low loss material, the microstrip architecture is suitable for the sensor realization and this happens when the propagation of the electromagnetic wave along a microstrip depends on the medium that surrounds it.

2.2 Critical Literature Review

In this study 7 references are reviewed critically as illustrated in table 2.1.

Table 2.1: Critical literature review

Reference	Title	Remark
[15]	Microwave studies by perturbation of Ag thick film microstrip ring resonator u sing superstrate of bismuth strontium manganites	• microstrip ring resonators are widely used in many microwave devices, particularly in filters, mixers, oscillators, and couplers. • The interest of researchers and communication industry engineers to these structures has recently increased due to the application of ferroelectric thin-film substrates and high-temperature superconducting microstrip lines in ring resonator fabrication • it cannot be used either for arbitrary microstrip geometries or for a large dielectric constant of the substrate, and is not appropriate for high frequencies
[16]	Measurement of dielectric constant and loss factor of the dielectric material at microwave frequencies	• Rectangular and cylindrical waveguide cavities have been commonly used for a long time in characterizing low-loss materials as they offer a high quality factor. • However, performing material measurement with waveguides concurrently with another printed resonator has not been investigated yet and will be the goal of this work. • It is intended to use both structures simultaneously as a double-check procedure for measurement convenience and low fabrication cost.

[17]	The Complex Dielectric Constant of Pure and Sea Water from Microwave Satellite Observations	• The measurement of dielectric properties can be indirectly done by measuring the S-parameters of the sample under test. By implementing an algorithm which finds the zeros of the error function, the dielectric constants and the loss tangents of a material can be calculated from the measured reflection and/or transmission coefficients. • However they can only be used when a precisely machined connection between transmission line and sample under test is possible to be fulfilled. • In addition, risk of the probe damaging delicate structures of sample and the difficulty to measure small, fragile materials make contact measurements undesired in certain circumstances.
[18]	Measurement of Dielectric Material Properties	• Measuring dielectric properties of materials means measuring the complex relative permittivity,εr and the complex relative permeability,μr . • Both the real and imaginary parts are present in a complex dielectric permittivity; the real part of the complex dielectric permittivity is called the dielectric constant. • When an external electric field is applied to a material, there is some energy loss; the measure of this energy loss from the material because of the applied external electric field is the dielectric constant.

		• The imaginary and real parts of the complex permittivity have a ratio called the loss tangent, it is written as tanδ ;it is also called dissipation factor, tangent loss, and loss factor
[19]	Dielectric Characterization of Materials using a Modified Microstrip Ring Resonator Technique.	• Resonators are commonly used as precise instruments for electromagnetic properties of materials such as complex permittivity, permeability and the surface resistance at microwave frequencies • For very low loss materials the resonant technique is the only one enabling measurements with sufficient accuracy. Due to possible high Q-factor of the resonators, and resulting very high sensitivity, such resonators can be also used as sensors of different physical quantities that depend on complex permeability of a material under test. • Resonators are deployed for complex measurements of materials at microwave frequencies. At present dielectric resonators are frequently used for measurements of dielectric materials, ferrites and super conductors at microwave frequencies.

[20]	Microwave Engineering	• Another way for confirming the estimated ε_{eff} is to use the metallic enclosure which acts as a waveguide cavity with L-band standard dimensions operating at its dominant mode $TE_{10\delta}$. • When the cavity is perturbed by the material under test (MUT) the resulting resonance frequency will be deviated from its original resonance frequency. From this frequency shift the material properties can be evaluated using the Cavity-Perturbation theory. • However, through the following section the details of the dielectric constant extraction procedures will be illustrated.
[21]	Rectangular Patch Resonator (RPR) Sensor for Characterization of Biological Materials.	• RPR sensors for microwave characterization of biological materials. • Used as biosensor for non-invasive testing and medical applications to characterize the electric properties of various biological materials. • Measurement showed that the complex dielectric properties obtained by this technique are good agreement with simulations.

[22]	A Novel Symmetrical Split Ring Resonator Based on Microstrip for Microwave Sensors	• Many methods have been proposed and used material characterization. These methods can be categorized as near filed sensors, transmission line, free-space methods, and resonant cavity. • Even though the microwave sensors are deployed for dielectric measurements for materials characterization, they are also used for measuring chemical reactions, humidity, and paramagnetic impurities. The main advantages of the microwave resonators used as sensors are: high precision level, high Q-factor, easy to design and fabricate, safe to use, reliable, low-cost, high measurement performance and sensitivity, and operating at various distinguished microwave frequencies.
[23]	A Brief Review of Measuring Techniques for Characterization of Dielectric Materials.	• The resonant methods can characterize the material at single or with some discreet frequency points. In this method a dielectric material used as a resonant element but it limited only for low loss test samples, some examples are; dielectric, planar and split resonators methods. • Other method is perturbation method, in which a sample is placed into a resonant cavity that causes the perturbation, resulting resonant frequency shift. This method is suitable for lower and moderate-loss samples