MATERIAL CHARACTERIZATION USING MICROWAVE RESONANT SENSOR

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ABSTRACT

Material Characterization is an important field in microwave engineering since it is involved in several systems and applications. 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. Nowadays some products that are available in markets and malls have prohibited or unhealthy ingredients that can effect on consumers health. To save consumers from being affected by these products, it is important to provide a device that can identify and characterize some kind of food we eat every day. A review of dielectric material properties and currently available measurement methods is included. Double ring resonant with 1 GHz microstrip design is presented for the measurement of thin and low-loss materials such as chicken, beef and fish. 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 study measurement of a sample of meat shows that when the thickness of the sample increases, the effective permittivity also increases. Measurement results in this thesis shows that Q-factor of the resonant decreases when overlay the double ring with meat sample. Material characterization is very important since it is employed in different fields such as agriculture, industries in food processing, geo-science, bio-engineering, pharmaceutical industry and in food manufacturing. Material characterization provides useful information to improve the design, processing, quality and control of product.

ABSTRAK

Pencirian bahan adalah bidang yang penting dalam kejuruteraan gelombang mikro kerana ia terlibat dalam beberapa sistem dan aplikasi. Pencirian bahan menggunakan gelombang mikro penderia bergema dianggap diantara satu ciri bahan yang diperolehi. Kaedah bergema biasanya mempunyai ketepatan lebih tinggi dan sesitiviti daripada cara lain, dan ia mudah untuk bahan-bahan kehilangan yang rendah. Ketika ini beberapa produk yang didapati di pasaran dan pusat beli-belah yang di larang atau bahan-bahan tidak sihat yang boleh melaksanakan di kesihatan pengguna. Untuk menyelamatkan pengguna daripada terjejas oleh produk-produk ini ia adalah penting untuk menyediakan satu alat yang boleh mengenal pasti dan ciri-ciri beberapa jenis makanan yang kita makan setiap hari. Kajian semula sifat dielektrik dan kaedah pengukuran yang ada sekarang dimasukkan Gandaan Gegelang resonan dengan 1 mikro jalur GHx reka bentuk dibentangkan untuk ukurang bahan-bahan kurus dan kerugian yang kecil seperti ayam, daging, dan ikan. Reka bentuk ini berdasarkan kepada simulasi elektromagnetik dalam soal frekuensi resonan, factor kualiti dan ketelusan. Reka bentuk simulasi, proses rekaan dan ukuran di ilustrasikan dalam kajian ini. Perbandingan antara keputusan simulasi dan ukuran ditunjukkan dalam kajian ini. Perbandingan antara keputusan simulasi dan ukuran ditunjukkan dalam kajian ini. Dalam ukuran kajian ini satu sampel yang digunakan sedemikian, apabila ketebalan peningkatan sampel daging yang diambil pakai ini, ketelusan berkesan juga meningkat. Ukuran mengakibatkan tesis ini menunjukkan bahawa factor-Q pengurangan bergema apabila melapisi gegelang berganda dengan sampel itu. Pencirian bahan amat penting sejak ia diambil bekerja dalam pelbagai bidang seperti pertanian, industry di pemprosesan makanan, sains geo, industri farmaseutikal dalm kejuruteraan bio dan penghasilan makanan. Pencirian bahan menyediakan maklumat berguna memperbaiki reka benturk, pemprosesan, kualiti dan kawalan produk.

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CHAPTER 1

INTRODUCTION

1.1 Project Background

Characterization of material is an essential field in microwave engineering since it is engaged in several systems and applications ranging from high-speed circuits to satellite and telemetry applications [1]. Material characterization using Microwave resonant sensor is a measurement technic using microwave frequencies, which 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. The resonant method depends on frequency and quality factor of a dielectric resonator with given dimensions are determined by its permittivity and permeability [2].

Dielectric properties are very important in our daily life, which is using in different fields such as agriculture, industries in food processing, geo-science, bio-engineering and pharmaceutical industry. Specially, in food manufacturing with advance technics, improvement in dielectric properties it is being use to get high-quality grains, fruits, vegetables, and meat and dairy products [3]. Food is not good dielectric material (neither good conductor nor an insulator) and its polarization is related with energy absorption & its dielectric constant [4]. For food, meat is one of the most main sources of proteins along with many essential amino acids, for human's body. By a rise of high-quality meat demand day-by-day, manufacturing has modified new developments and methods during the past few years. Using a dielectric method for freshness and quality valuation of meat has several advantages, such as: it is non-destructive, easy, rapid, effective and reliable [5].

1.2 Problem statement

Not all people enjoy all kind of food due to negative impact may cause it for them such as allergic and Food Poisoning. Rotten of some products inside stores of industries and markets can be reason of some healthy problems. Sale some products that have prohibited ingredients also effect on consumers health. To avoid healthy problems, it is necessary to provide a device that can identify and characterize some kind of food we eat every day such as beef, chicken and beef. This device will make it easy for people to choose the suitable food for their health. In addition this device is very useful since it is engaged in various systems and applications. This device can be also used by food industries to check the validity of food. Material characterization provides useful information to improve the design, processing, quality and control of product.

1.3 Objectives of the project

The main objective of this project is to develop a device that can identify material properties through Microwave Resonant Sensor. Therefore, the objectives as below should be achieved:

- To characterize material properties through Microwave Resonant Sensor.
- To analyze the material properties through electromagnetic simulation in terms of permittivity, frequency and quality factor.
- To validate the simulated results through experimental setup and evaluation in laboratory.

1.4 Project Scope

The main purpose of this project is to develop a device that can identify material properties through electromagnetic simulation in terms of resonant frequency, quality factor and permittivity. This device is limited to measure thin and low-loss materials only such as beef, chicken and fish. In this study current methods that use to identify the material properties are considered. Design of a microstrip ring resonant (MMR) at 1 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 Thesis Structure

This thesis consists of five chapters which are categorized as below:

Chapter 1: Introduction-This chapter introduces and explains the purpose of this project, presents the problem formulations, thorough and as well as detail information about the Material Characterization using Microwave Resonant Sensor will be discussed.

Chapter 2: Literature Survey- This chapter provides a detailed background of the material characterization and methods used to identify material properties. It also provides information about the techniques use to characterize material properties.

Chapter 3: Methodology- This chapter describes the methods and procedures used to design this project in details as well as flow charts, provide specifications, discussion and processing technique.

Chapter 4: Result and discussion- This chapter illustrates and analyzes the result of this project and discusses the possible further improvements of the developed device.

Chapter 5: Conclusion and recommendation- This chapter presents the conclusion of the project. The strengths and limitation of the project will be highlighted as well. Furthermore, some recommendations for future works will be provided.

CHAPTER 2

LITERATURE REVIE

2.1 Introduction

Several techniques were developed to characterize the dielectric properties of materials. These days' researchers are working on the characterization of dielectric materials using different resonance and transmission/reflection techniques such as coaxial line technique, CPW coplanar waveguide, cavity perturbation, parallel plate capacitor, microstrip line and ring resonator techniques.

M. S. Kheir, H. F. Hammad, and A. S. Omar developed ring resonator with a rectangular waveguide cavity to measure the dielectric constant of liquids, they calculated the dielectric constant by measuring the resonance frequency of the hybrid resonator. They placed the liquids in the cavity area, and the response was measured in the frequency range of 500MHz to 3GHz [1].

M.T. Jilani, W. P.Wen, M.A. Zakariya and L.Y. Cheong designed micro-strip ring resonator based sensing technique for meat quality, at 1 GHz frequency the micro-strip ring-resonator was designed on HFSS simulation software, they measured the permittivity by placing a sample of meat over ring-resonator. From HFSS simulation they have studied S-parameter for MRR with overlay meat sample with various thickness ranges. From their results it can be observed that as the thickness of overlay layer increases, the effective permittivity also increases. While the simulation result of S12 at 1.02 GHz , 2.05 GHz and 3.06 periodic resonances, seems much lossy [6].

A. Kumar and S. Sharma evaluated the dielectric constant and loss factor of a homogeneous dielectric material using rectangular shaped perturb cavity. By placing the sample in the center of the cavity resonator they calculated the permittivity from the shift in the resonant frequency and Q-factor. The permittivity was measured in the frequency range of 11.4 GHz to 11.66 GHz [7].

S. Seewattanapon and his group developed a folded ring resonator sensor to measure dielectric constant. They measured the dielectric constant by placing the material in a very compact area, and they evaluated the response in the frequency range of 500MHz to 4.5 GHz was sufficient to cover three resonant modes [8].

X.Zhu and his group designed complementary split ring resonators at terahertz frequencies to characterize substrate material. They have done the measurement evaluation by comparing the results with those obtained by using two well-known standard techniques. Measurement was done under range of frequency from 2GHz to 40 GHz [9].

N.Aouabdia, N.E.Belhadj and G.Alquie developed Rectangular patch resonator (RPR) sensors for microwave characterization of biological materials. RPR Used as a biosensor for non-invasive testing and medical applications to characterize the dielectric properties of various biological materials. Their measurements showed that the complex dielectric properties obtained by this technique are in good agreement with simulations using C.Gabriel & al comparative data [10].

2.2 Critical Literature Review

In this study 20 references are reviewed critically as illustrated in table 2.1.

Table 2.1. Critical literature review

Reference	Title	Remark
1	Measurement of the Dielectric Constant of Liquids Using a Hybrid Cavity-ring Resonator	• Designed ring resonator with a rectangular waveguide cavity to measure the dielectric constant of liquids. • Dielectric constant was calculated by measuring the resonance frequency of the hybrid resonator. • The liquids were placed in the cavity area, and the response is measured in the frequency range of 500MHz to 3GHz.
6	Microstrip Ring Resonator Based Sensing Technique for Meat Quality	• Designed micro-strip ring resonator based sensing technique for meat quality. • 1 GHz micro-strip ring-resonator is designed on HFSS simulation software. • By placing a sample of meat over ring-resonator the permittivity is measured.
7	Measurement of Dielectric Constant Loss Factor of the Dielectric Material Microwave Frequencies	• Developed rectangular shaped perturb cavity to evaluate the dielectric constant and loss factor of a homogeneous dielectric material. • By placing the sample in the center of the cavity resonator Permittivity is calculated from the shift in the resonant frequency and Q-factor. • The permittivity was measured in the frequency range of 11.4 GHz to 11.66 GHz .

Reference	Title	Remark
8	A Micro-strip Folded Resonator Sensor for Measurement of Dielectric Constant	• Developed a folded ring resonator sensor to measure dielectric constant. • Dielectric constant is measured by placing the material in a very compact area. • The response is measured in the frequency range of 500MHz to 4.5 GHz.
9	Dielectric Characterization of Materials using a Modified Microstrip Ring Resonator Technique	• Developed a ring-resonator technique for measurement of nondestructively, the permittivity and loss tangent of dielectric materials. • Measurement was evaluated by comparing the results with those obtained by using two well-known standard techniques. • Measurement is done from 2GHz to 40 GHz.
10	Rectangular Patch Resonator Sensors For Characterization of Biological Materials	• Rectangular patch resonator (RPR) sensors for microwave characterization of biological materials. • Used as a biosensor for non-invasive testing and medical applications to characterize the dielectric properties of various biological materials. • Measurements showed that the complex dielectric properties obtained by this technique are in good agreement with simulations.
12	A Circular Patch Resonator for the Measurement of Microwave Permittivity of Nematic Liquid Crystal	• Designed Circular Patch Resonator for the Measurement of Microwave Permittivity of Nematic Liquid Crystal. • Measurement of resonant frequencies and quality factors with characterization of BL006 (a nematic liquid crystal) over the frequency range of 4.8–8.7 GHz.

Reference	Title	Remark
13	Complementary Split- Ring Resonators for Measuring Dielectric Constants and Loss Tangents	• A noninvasive e planar complementary split-ring resonator (CSRR) for measuring the dielectric constants and loss tangents of material. • Using CSRR sensor which was operating in the 1.8 to 2.8 GHz band is fabricated and tested for verification. The measurement errors in the dielectric constant are less than 7.6%.
14	Microwave Measurements of Dielectric Properties Using a Closed Cylindrical Cavity Dielectric Resonator	• Microwave measurements of the dielectric constant and loss tangent of homogeneous • Isotropic samples in rod form, using a closed cylindrical cavity resonator. Measurement accuracy is assessed by comparing the results with those obtained using other well-known techniques. • Used Styrofoam as the sample support has the advantage of having a low dielectric constant (ε'= 1 .03).
15	A dielectric resonator method of measuring dielectric properties of low loss materials in the microwave region	• A technique for the measurement of dielectric properties of low loss and homogeneously isotropic media in the microwave region. • Measuring structure is a resonator made up of a cylindrical dielectric rod and conducting plates measured within a frequency range of 3 GHz.

Reference	Title	Remark
16	Design of Singly Split Single Ring Resonator for Measurement of Dielectric Constant of Materials using Resonant Method	• Measure the dielectric constant using resonant method. • Measured dielectric constants of different materials was done with a singly split single ring resonator. • At 1.56GHz and 1.5HGz the dielectric constant was 2.9 and 2.5 respectively .
17	Design of a Cylindrical Cavity Resonator for Measurements of Electrical Properties of Dielectric Materials	• Measure the dielectric constant of semi-solid which is a kind of sand using cylindrical cavity resonator. • Using one port reflection coefficient was performed in HFSS and practice. • Designed at 1.2 GHz by copper and ferromagnetic material .
18	Ring Resonator with single gap for Measurement of Dielectric Constants of Materials	• Measured the dielectric constant of material using ring resonant with single gap. • 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. • Measured the resonant frequency of the ring resonator between 0.5GHZ and 2.5GHZ .
19	Dielectric Characterization using Meander Resonator sensor	• Measurement of dielectric constant using microstrip meander resonator sensor. • The sensor is implemented using planar microstrip technology. Resonator was designed using ADS for a fundamental frequency of 1 GHz .

Reference	Title	Remark
20	Measurement of Complex Permittivity using Planar Resonator sensor	• A Microstrip loop resonator sensor designed to determine the dielectric constant of a liquid. A dielectric material is placed above micro-strip ring resonator. • Resonator sensor designed for 1GHZ for different structure .
21	Microstrip Transmission Line Sensor for Rice Quality Detection : An Overview	• Micro-strip transmission sensor for rice quality detection. Applying the different principles and methods. • Measurement with Vector Network Analyzer the reflection coefficient reading gives us the measurement of broken rice .
22	Novel Microwave Microfluidic Sensor Using a Microstrip Split-Ring Resonator	• Microwave micro fluidic sensor is proposed to detect and determine the dielectric properties of common liquids. • A microstrip split-ring resonator with two gaps is adopted for the design of the sensors. • At 3 GHz, very good agreement is demonstrated between simulated and measured results.

Reference	Title	Remark
23	A Generalized Rectangular Cavity Approach for Determination of Complex Permittivity of Materials	• A novel cavity-based unified approach to measure the complex permittivity of dielectric material. • Samples placed in the E-plane of a rectangular cavity. • Using MATLAB to obtain the results.
24	Characterization of Substrate Material Using Complementary Split Ring Resonators at Terahertz Frequencies	• Complementary split ring resonators at terahertz frequencies to characterize substrate material. • Measurement the complex permittivity for Silicon substrate from 110GHz to 180GHz by using backward-wave oscillator (BWO) spectrometers. • Measurement results show that the dielectric properties of Silicon substrate remain almost the same as that provided by semiconductor foundry at microwave frequencies.
25	Measurements of Planar Metal–Dielectric Structures Using Split-Post Dielectric Resonators	• Split-post dielectric resonators for the measurement of the complex permittivity and the complex permeability of planar. • By moving several small metamaterial is scanned in the cavity electromagnetic field samples inside the split-post dielectric resonator. • The results are permittivity tensor components of 4.43 to 4.59 and loss tangent is smaller than 20µ at frequency below 5GHz.

2.3 Dielectric Measurement Techniques

Dielectric measurement techniques are basically depended on several factors such as frequency and dielectric constant. Electrical characteristics are dependent on dielectric properties which are different form material to other material. And this dielectric behavior of material can be variable with testing frequency, temperature, sample size etc. The dielectric constant is dependent on frequency; as frequency increases it decreases, so if we measure a material at lower frequency its dielectric constant will change from high frequency measured value [11]. In table 2.2, generic comparison of discussed techniques is presented.

Table 2.2: Comparison of Most Popular Dielectric Measuring Techniques [11].

Method	Measure	Advantages	Disadvantages
Coaxial Probe	ε_r	• Broadband frequency • Simple and convenient (nondestructive) • Best for semi-solids or liquids • Simple sample preparation • Isotropic and homogeneous material • High accuracy for high-loss materials	• Air gaps causes errors • Repetitive calibrations
Transmi -ssion line (wavegu ide)	ε_r , μ	• High frequency • Support for both solids & liquids • Anisotropic material	• Cannot use below few GHz, due to practical sample length limitation • Sample preparation is difficult (fills fixture cross section)

Method	Measure	Advantages	Disadvantages
Free Space	ε_r , μ	• Wide frequency range support • Non-contacting • Easy sample preparation • Moderate accuracy for high-loss & low-loss • Best for large flat and solid materials • Useful for high temperature	• Diffraction problem (from material edges) • Low end limited by practical sample size
Rsonant Cavity	ε_r , μ	• Support for both solids & liquids • Most accurate method • Suitable for low loss materials • No repetitive calibration procedure • High temperature capability • Best for low loss materials	• Measurements at only single or at resonant frequency • Suitable for small size samples
Parallel Plate	ε_r	• Simple, cost-effective and rapid • No special sample handling • Can used for Solid/Liquid • High temperature measurements	• Low quality factor • Air gap causes error