DESIGN OF COMPLIMENTARY SPLIT RING RESONATOR BASED MICROWAVE RESONATOR SENSOR FOR DIELECTRIC MATERIALS CHARACTERIZATION

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DESIGN OF COMPLIMENTARY SPLIT RING RESONATOR BASED MICROWAVE RESONATOR SENSOR FOR DIELECTRIC MATERIALS CHARACTERIZATION

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This report is submitted in partial fulfilment of the requirements for the degree of Bachelor of Electronic Engineering with Honours

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DECLARATION

I declare that this report entitled "Design of Complimentary Split Ring Resonator based Microwave Resonator Sensor for Dielectric Materials Characterization" is the result of my own work except for quotes as cited in the references.

Signature : ....

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Date : 4 JANUARY 2022

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 Bachelor of Electronic Engineering with Honours.

Signature : ....

Supervisor Name : MAIZATUL ALICE BINTI MEOR SAID

Date : 14.1.2022

DEDICATION

This thesis is dedicated to my beloved parents and family members who always give moral supports and encouragements to me throughout whole study journey. The special dedication for my supervisor, Dr. Maizatul Alice Binti Meor Said and also my friends who guide me and help me along development of this project until it has been successfully completed at last.

ABSTRACT

There are various types of techniques that can be applied for determining dielectric properties and each of them has its own advantages and limitations. A CSRR model has been introduced in order to ensure the accurate and sensitive measurements for different kinds of dielectric materials characterization. The objectives are to design and simulate the project in order to understand the relationship between the resonance frequency and permittivity properties of dielectric materials. Therefore, it has been developed into the hardware to analyze the effects of materials tested. The expected outcome shown as the higher the permittivity of tested dielectric material, then the lower the resonant frequency shifted. This sensing technique by CSRR gains the high sensitivity and accuracy measurements of dielectric materials characterization in a way of low cost, compact in size and simplicity when compared to other conventional sensing techniques. It also helps to avoid wasting in resources as well as save time during the manufacturing process. It will be one of the good choices for various field of industry in dielectric properties measurement.

ABSTRAK

Terdapat pelbagai jenis teknik yang boleh diaplikasikan untuk menentukan sifat dielektrik dan setiap satu daripadanya mempunyai kelebihan dan kelemahan tersendiri. Model CSRR telah diperkenalkan untuk memastikan ukuran yang tepat dan sensitif untuk pelbagai jenis bahan dielektrik. Objektifnya adalah untuk mereka bentuk dan mensimulasikan projek untuk memahami hubungan antara frekuensi resonans dan sifat kebolehtelapan bahan dielektrik. Oleh itu, ia telah dibangunkan menjadi perkakasan untuk menganalisis kesan bahan yang diuji. Hasil yang dijangkakan ditunjukkan sebagai semakin tinggi ketelusan bahan dielektrik yang diuji, maka semakin rendah frekuensi resonan yang beralih. Teknik penderiaan oleh CSRR ini memperoleh kepekaan dan ketepatan yang tinggi bagi ukuran atas bahan dielektrik dengan cara kos yang rendah, saiz yang padat dan kesederhanaan jika dibandingkan dengan teknik penderiaan konvensional yang lain. Ia juga membantu mengelakkan pembaziran sumber serta menjimatkan masa semasa proses pembuatan. Ia akan menjadi salah satu pilihan yang baik dalam pelbagai bidang industri untuk pengukuran sifat dielektrik.

ACKNOWLEDGEMENTS

I would like to take this opportunity to express my sincere gratitude to all the people who always support and guide me on the completion of my thesis. Besides that, I would like to express my deepest appreciation for the advices and suggestions given from my supervisor, Dr. Maizatul Alice Binti Meor Said to accomplish my project. Finally, I would like to thank my parents and friends that have encouraged me all the time.

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LIST OF SYMBOLS AND ABBREVIATIONS

CSRR - Complimentary Split Ring Resonator

MUT - Material under Test

TEM - Transverse Electric and Magnetic

mm - millimeters

VNA - Vector Network Analyzer

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CHAPTER 1

INTRODUCTION

This chapter will briefly figure out the overall project idea such as its background, problem statement, objectives, scope and the outline in the thesis.

1.1 Background of Project

Recently, the dielectric properties are very significant for various industry fields such as food industry, health care, chemical industry, electronics industry, etc. Every dielectric material has different properties that can be determined in permittivity, permeability and so on. Thus material characterization approach based on radio frequency and microwave measurements is highly demanded. According to the *Rammah A. Alahnomi* (2019), there are various types of techniques that can be applied for determining dielectric properties and each of them has its own advantages and limitations. Some examples include the coaxial probe sensor and waveguide resonator which achieve in high sensitivity, however they require higher cost to fabricate due to the complexity of design structures and also have a larger size when compared to planar sensor [1]. Therefore, a complementary split ring resonator (CSRR) based microwave sensor has been proposed which will resonate at 2.5GHz under unloaded condition for accurate measurement of dielectric materials. The sensitivity of this sensor depends on the relative change of frequency shifting that corresponds to the relative change of the tested material permittivity. Throughout this whole designing and simulation process, a desired outcome can be accomplished that the sensing technique is in a way of comprising low cost, compact in size, ease of fabrication as well as simple sample preparation at the same time.

1.2 Problem Statement

The issue faced is the limitations existing in conventional devices in terms of complexity, size, cost and also sensitivity. Although some conventional devices are high sensitivity but they require higher cost and have larger size with complex structure inside than planar sensor. In this paper, a CSRR model has been introduced in order to ensure the accurate and sensitive measurements for different kinds of dielectric materials characterization.

1.3 Objectives

There are three main objectives will be achieved in this project.

a) To design a complementary split ring resonator (CSRR) based microwave sensor.

b) To simulate the resonator's circuit via CST Microwave Studio Software.

c) To analyze the relationship between the resonance frequency and permittivity properties of dielectric materials.

1.4 Scope of Project

The CSRR project is developed with high sensitivity and accuracy in a simpler and low cost way due to the limitations faced in conventional sensors. This project involves the application of CST Microwave Studio Software for simulating and analyzing the resonator's circuit. Besides that, it also measures relative change in resonance frequency which corresponding to the relative change on permittivity of tested dielectric materials of Rogers RT5880, Rogers RO4350B and Rogers RO3010 with different dielectric constant. The effects may relate with the sensitivity of CSRR.

1.5 Thesis Outline

The subsequent chapters are listed as following: -

- Chapter 2 focuses on the knowledges and literature reviews from reliable research resources to have a better understanding of this project.
- Chapter 3 describes the methodology applied for the CSRR design project and its procedures. Meanwhile, the steps taken are considered during simulation of circuit via software.
- Chapter 4 will be discussed about the results obtained from the experiment. Analysis and detailed explanations are also gained in this chapter.
- Chapter 5 concludes the outcomes which regarding to this project and provides some recommendations in order to improve the project in the future.

CHAPTER 2

LITERATURE REVIEW

2.1 Dielectric Constant

The dielectric constant is defined as the relative permittivity or specific inductive capacity, property of an electrical insulating material (dielectric) equals to the ratio of the capacitance of a capacitor filled with the given material to the capacitance of an identical capacitor in a vacuum without the dielectric material [2]. It typically denoted by symbol ε, Equation 2.1.1 shown as following.

Equation 2.1.1

$$\varepsilon = \frac{C}{C_o} \quad , \quad C_o = \frac{\varepsilon_o A}{t}$$

Where:

- C = capacitance using the material as the dielectric capacitor
- C_0 = capacitance using vacuum as the dielectric
- ε_0 = Permittivity of free space (8.85×10^{-12} F/m i.e. Farad per metre)
- A = Area of the plate/sample cross section area
- T = Thickness of the sample

This is a dimensionless measurement which will be influenced by a few factors such as frequency, voltage, moisture and temperature, structure and morphology, etc [3].

2.2 Methods of Dielectric Constant Measurement

There are various types of methods for measuring the dielectric constant in materials. For instance, coaxial probe, transmission line, free space and also the resonant cavity technique [4]. Each technique has been reviewed in this chapter with reference to some articles and journals.

a) Coaxial Probe Method

This method is basically a truncated section of a transmission line which used to measure the reflection coefficient of materials. The electromagnetic field propagates along the coaxial line and reflection occurs when electromagnetic field encounters an impedance mismatch between the probe and MUT [5]. The MUT that is attached to it can be in solid, liquid or even the semi-solid form.

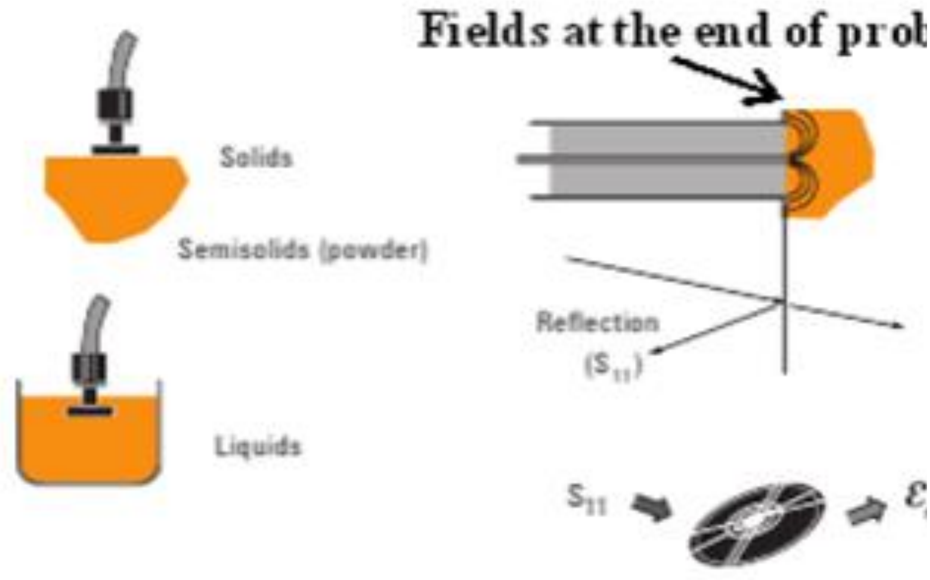

Figure 2.2.1: Open-ended Coaxial Probe Measurement Method

The reflected signal is then converted into relative permittivity via the software embedded in Vector Network Analyser (VNA). Reflection coefficient of MUT will be measured after calibrating the VNA by applying a reference material [6].

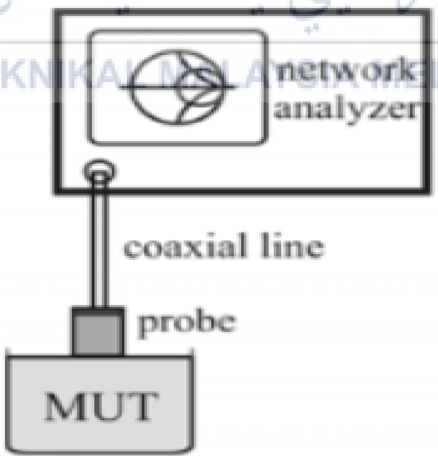

Figure 2.2.2: Permittivity Measurement System (CPM)

b) Transmission Line Method

In transmission line method, it allows to measure permittivity of different materials through the transmission line. A sample is placed in a coaxial airline or in a rectangular waveguide as Figure 2.2.3 below.

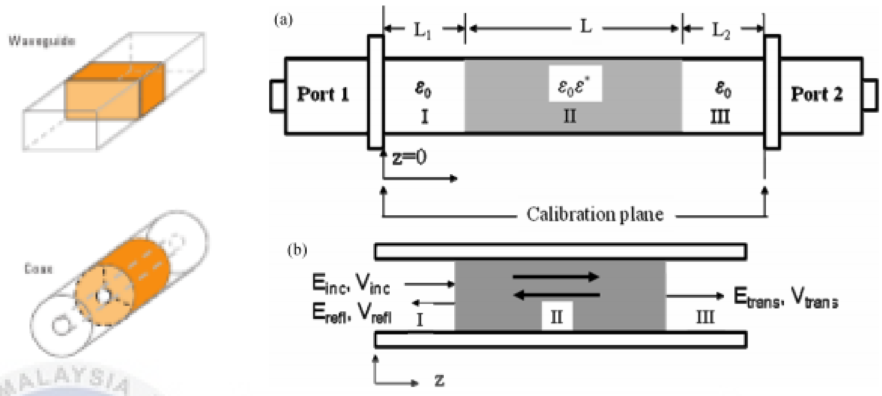

Figure 2.2.3: Two-port Transmission Line Measurement Method

The parameters of scattering matrix of a measured sample are found during analysis of electromagnetic field's distribution [7]. The fundamental propagation mode for waves inside it is called as Transverse Electric and Magnetic (TEM) mode which both fields are perpendicular to the direction of waves travelled. Besides that, this measurement system also consists of a VNA in order to acquire the two-port complex scattering parameters (S-parameters) and software is responsible for converting its measured S-parameters to complex permittivity [8].

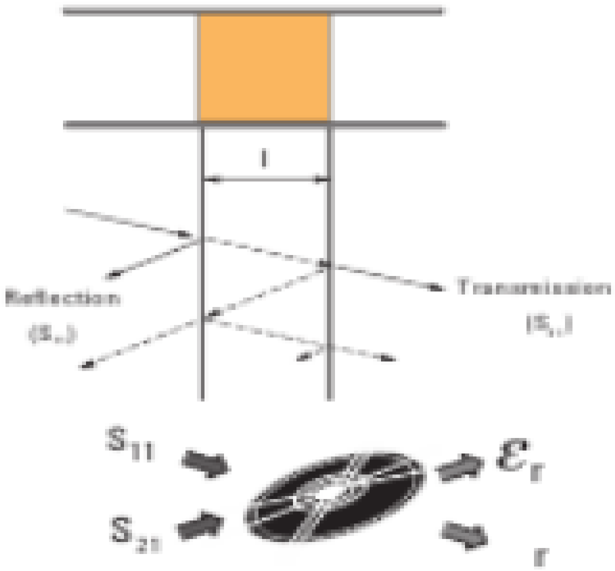

Figure 2.2.4: Permittivity Measurement System (TLM)

c) Free Space Method

Antennas have been utilized in this technique. Two ports of VNA are connecting to both sides of antennas which able to sense the propagation path of interest. In this way, different materials can be characterized by means of proper reconstruction algorithms. The behavior is characterized by four S-parameters (S_{11}, S_{12}, S_{21}, S_{22}) in transmission and reflection [9]. Extraction of electromagnetic properties from S-parameters is also achieved after the measurement. Its concept has contactless with the sample and configuration of FSM is shown as Figure 2.2.5.

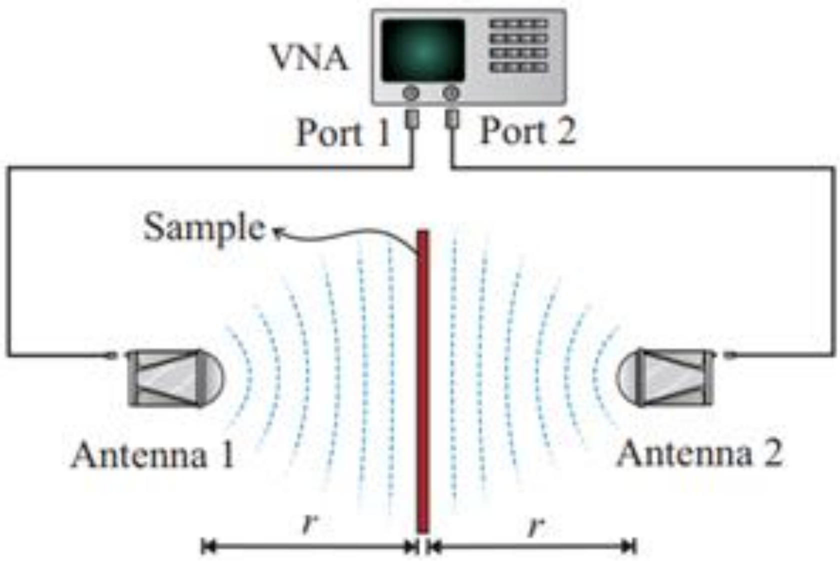

Figure 2.2.5: Free Space Measurement Method

d) Resonant Cavity Method

The cavity resonator is a hollow closed conductor. Similarly, a metal block has a cavity inside which contains electromagnetic waves reflecting back and forth between cavity's walls [10]. The measurement of dielectric constant is determined based on the resonant frequency and also quality factor that due to those inserted samples. The design provides a resonator to resonate at a particular frequency while the inserted sample occupies much smaller volume than it. The perturbation theory can be introduced in order to infer the real part of permittivity within sample from the observed shift in resonant frequency whereas the imaginary part of permittivity from the change in Q-factor of the resonator [11]. The calibration of VNA does not require for this method.

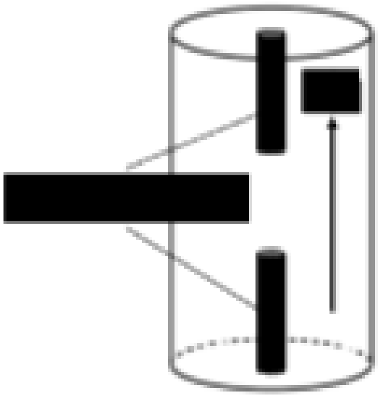

Figure 2.2.6: Resonant Cavity Measurement Method

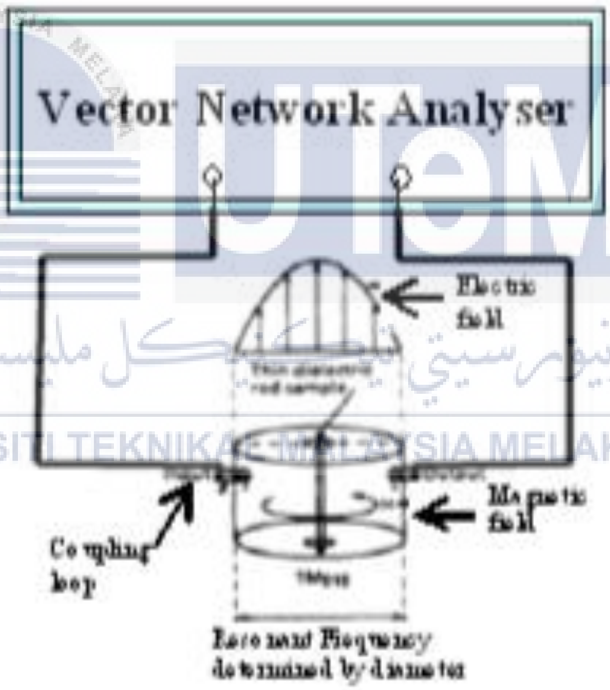

Figure 2.2.7: Permittivity Measurement System (RCM)

2.3 Comparison between Different Measurement Techniques

Table 2.3.1 below shows the comparison between the different permittivity measurement techniques in advantages as well as disadvantages. A simple summary for this subtopic also has been presented as Figure 2.3.1 and Figure 2.3.2 [12].

Table 2.3.1: The Comparison between Different Measurement Techniques

Techniques	Advantages	Disadvantages
Coaxial Probe	• Simple and convenient (non-destructive) • Well suited for semi-solids and liquids • High accuracy for high loss materials	• Air gaps cause errors • Less stable in cable • Repetitive calibrations
Transmission Line	• Broad frequency range • Supports for both solids and liquids • Ability in measuring magnetic materials	• Limited low end of band by sample length • Time-consuming • Difficult sample preparation (fills cross section of fixture)

Free Space	• High frequency • Non-contacting • Materials under high temperature can be used	• Limited low end frequency by sample size • Diffraction problem from edges • Requires large and flat sample
Resonant Cavity	• High accuracy • Simple sample preparation • Best for low loss materials	• Restriction to only single frequency measurement • Suitable for small dimension sample

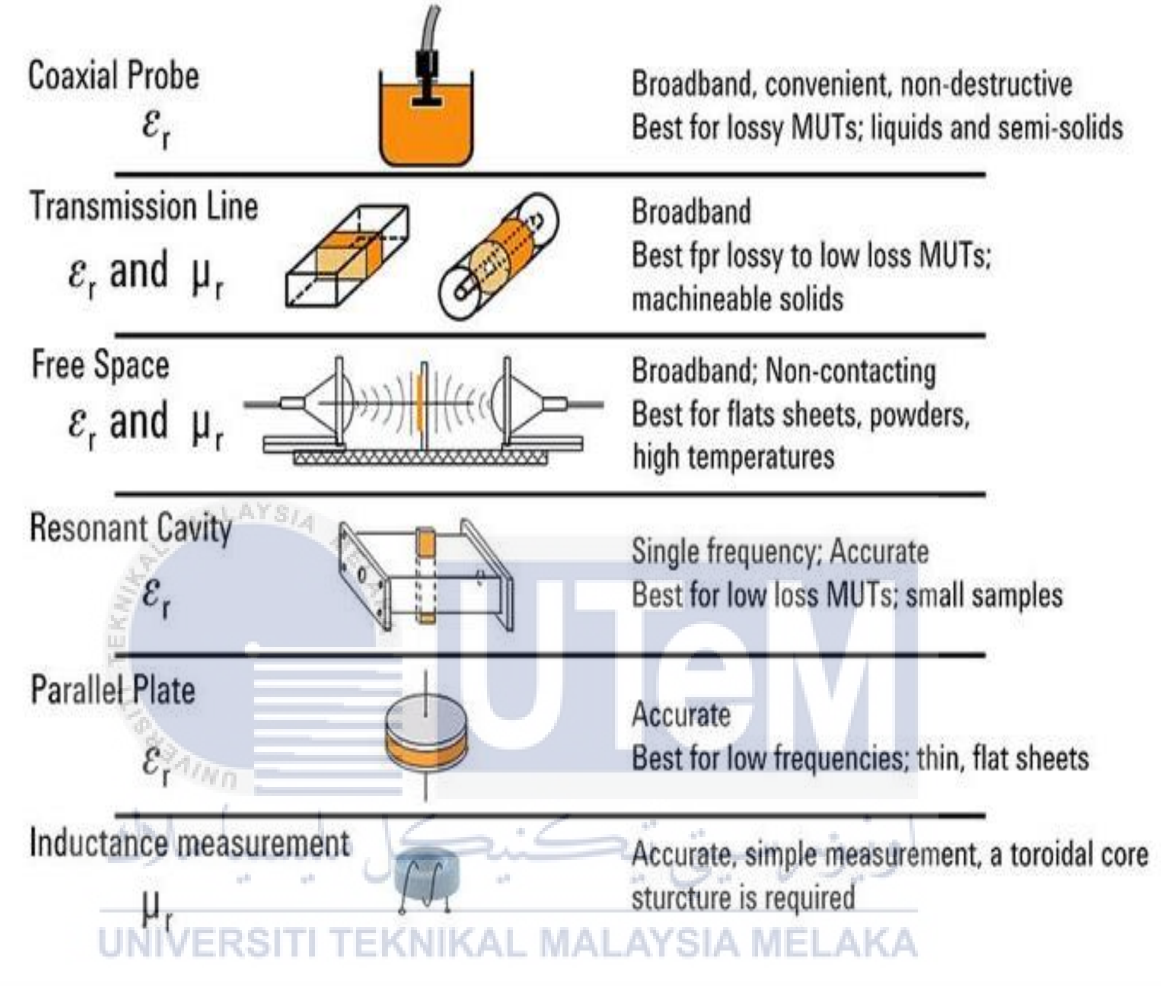

Figure 2.3.1: Comparison between Different Measurement Techniques

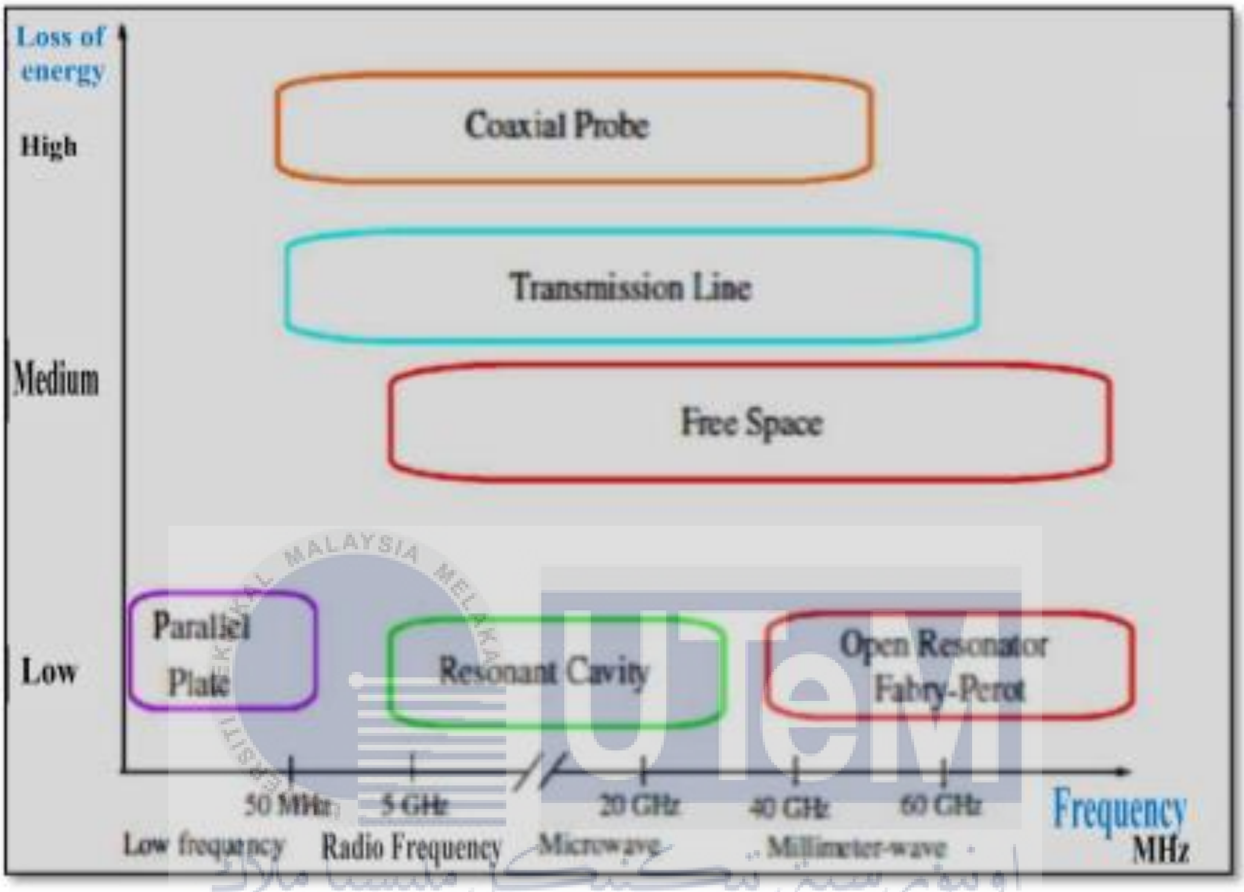

Figure 2.3.2: Different Measurement Techniques Relying on Frequency Applied

Based on the researches above, those techniques can be classified into two categories. One is known as resonant method while another one is known as broadband method. Both differences have been discussed as following [4].

a) Resonant Method

The resonant cavity technique is an example for this method. Basically, it supports high impedance environment. This is possible to make a reasonable measurement with small sample and suitable for low loss materials. The measurement is restricted at only single frequency.

b) Broadband Method

The examples of broadband method such as coaxial probe, transmission line and also free space technique. This method supports low impedance environment, large sample required for reasonable measurement but it allows to measure at any frequency.

Each of them has their own characteristics and specifications which bring along pros and cons when applying it. In order to achieve a high accuracy sensing technique in a way of comprising low cost, compact in size, ease of fabrication as well as simple sample preparation, therefore a CSRR will be developed in this project. So it can overcome the rising issues in conventional measurement techniques above.

2.4 Resonance

The resonance occurs when capacitive reactance gains equivalently with the inductive reactance in magnitude and frequency at which they hold for specific circuit is termed resonant frequency of that circuit. Resonant frequency provides the maximum amplitude of frequency response, its equation in simple RLC circuit that can represent a simple resonator is generally written as Equation 2.4.1 where L and C stand for inductance and capacitance respectively.

Equation 2.4.1

$$f_r = \frac{1}{2\pi\sqrt{LC}}$$

Due to the principle of perturbation, when resonator is filled with samples that have different permittivity and permeability, the distributions of electric field and magnetic field will be disturbed and hence make a changing in capacitance and inductance of the equivalent circuit [13]. Equation 2.4.2 shows the relationship between the dielectric properties to its resonant frequency.

Equation 2.4.2

$$\frac{\Delta f_r}{f_{r\_unloaded}} = \frac{\int_{v}^{0} \Delta\varepsilon \mathbf{E}_1 \mathbf{E}_0 + \Delta\mu \mathbf{H}_1 \mathbf{H}_0 dv}{\int_{v}^{0} \varepsilon_o |\mathbf{E}_0|^2 + \mu_o |\mathbf{H}_0|^2 \, dv}$$

Where:

- $f_{r\_unloaded}$ = resonant frequency when the resonator is unloaded
- Δf_r = shift of resonant frequency when resonator is loaded with sample
- ε_o = free space permittivity
- μ_o = free space permeability
- $\Delta\varepsilon = \varepsilon_o(\varepsilon_r - 1)$ is the change in permittivity
- $\Delta\mu = \mu_o(\mu_r - 1)$ is the change in permeability
- E_0 & H_0 = electric and magnetic fields in unloaded condition
- E_1 & H_1 = disturbed fields
- v = perturbed volume

In addition, Figure 2.4.1 represents a graph of the relationship between resonant frequencies versus relative permittivity values [14].

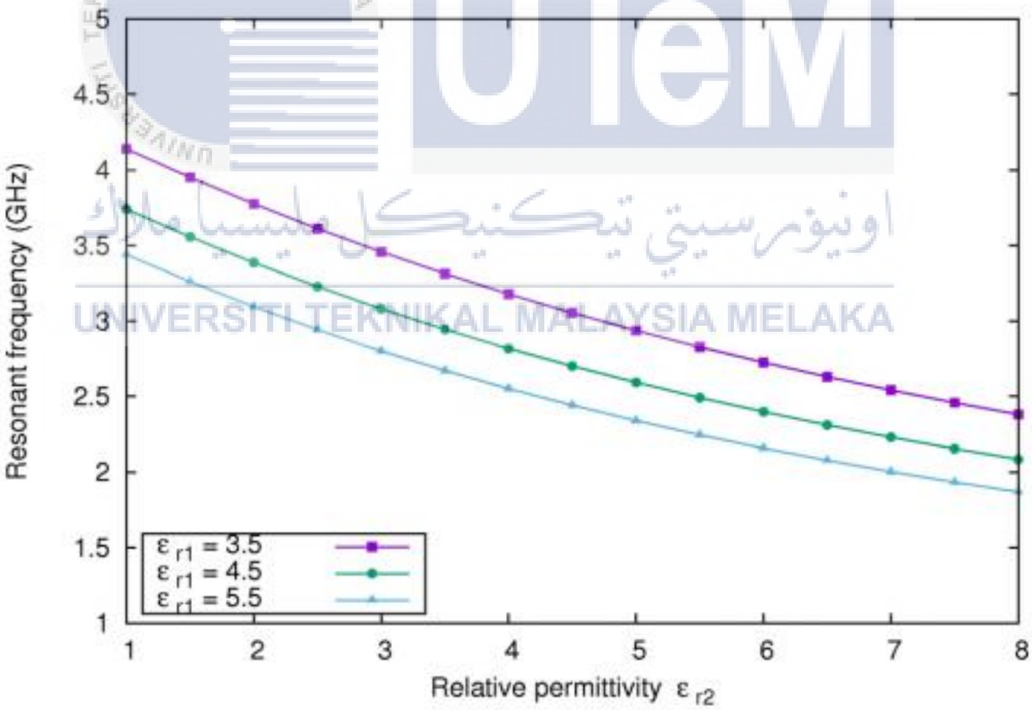

Figure 2.4.1: Relationship between Resonant Frequencies versus Relative Permittivity Values

2.5 CSRR

Metamaterials are artificial materials which exhibit singular electromagnetic properties that do not find in nature or in their constituents taken separately. The feature is the possibility to control or modify permittivity and permeability of those materials in order to obtain a behaviour adapted for specific application [15]. Complimentary split ring resonator (CSRR) as left-handed material consists of a dual structural design of split ring resonator to build compact microstrip low pass filter, stop band filter or band pass filter for microwave frequency uses. It has been studied as alternative way instead of conventional split ring resonator with the aim of miniaturization. This will allow the easy realization of shunts and the possibility of mounting active and passive lumped components. In the microstrip technology,

Figure 2.5.1: Geometry of a CSRR Unit Cell and its Lumped-element Equivalent Circuit

CSRR is etched on the ground plane while beneath the microstrip with their axes parallel to the vector of the electric field. Thus it is contributing to the negative effective dielectric permittivity of the structure. Moreover, for negative effective permeability is also introduced where can be achieved by periodically etching capacitive gaps in the conductor strip.

The parameters that will influence magnetic resonance of CSRR include the origin of capacitance and inductance. There are two contributions which one arising from the splits and the other from the gap between the two concentric rings. Capacitance due to the splits can prevent current flow around the rings but the mutual capacitance between the two rings allows the current flow through this structure. Inductance can arise from conducting rings. In addition, different physical dimensions of CSRR affect the resonant frequency. The varying in dimensions, the changing in the magnetic resonant frequency due to capacitance. The width of the split and the distance of the gap will also increase or decrease resonant frequency. The increasing distance of gap then the increasing resonant frequency acquired. This is because its larger gap distance reduces the mutual capacitance of the equivalent circuit. Hence the design of CSRR structure will be considered based on these aspects since the resonant frequency can be affected [16].

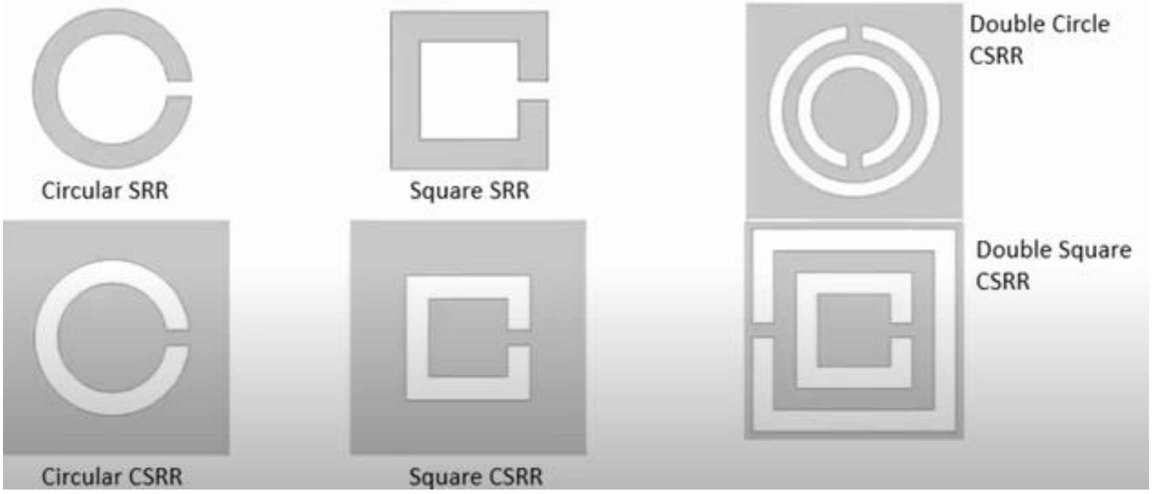

Figure 2.5.2: Types of Resonators

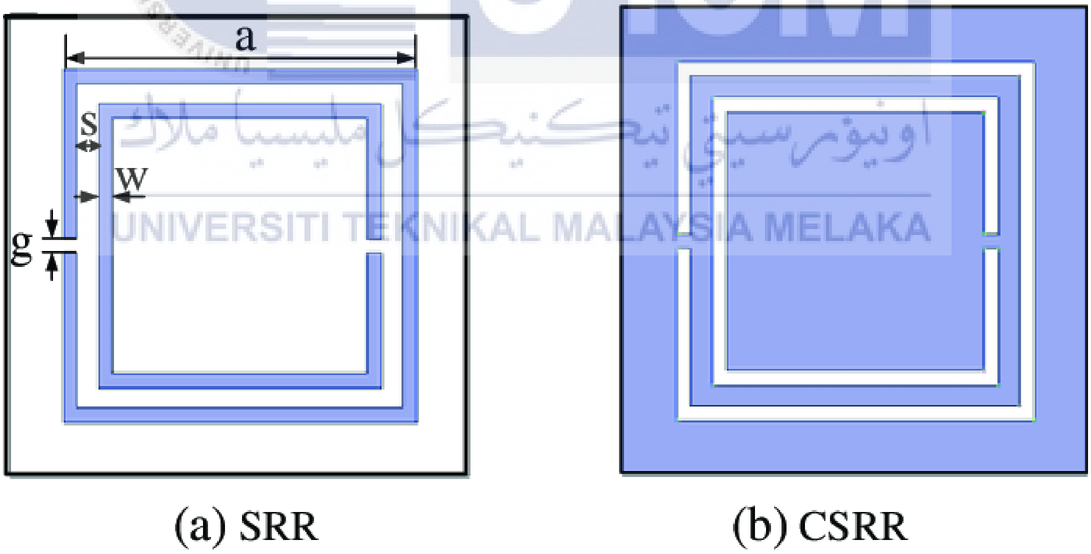

Figure 2.5.3: The SRR and CSRR Structure

2.6 Research of CSRR Model

There are many researches have been done on the performances of CSRR model for pass few years. These researches are mainly focused on the aspect of several techniques applied and also the ideas to design the CSRR proposed in software and hardware. The table below shows that various works on its principles and related information.

Table 2.6.1: Research Papers of CSRR

Authors, Year	Research Title	Contents
SpecialChem SA, 2020 [3]	What is a Dielectric Constant of Plastic Materials	$\varepsilon = \frac{C}{C_o}$, $C_o = \frac{\varepsilon_o A}{t}$
Giovanni D'Amore, 2017 [4]	Six techniques for measuring dielectric properties	The classification of CSRR as resonant method.
Jassim M. Thabit and Hawkar B.Bakir, 2016 [12]	Measuring of Relative Dielectric Permittivity to Calculate Electromagnetic Wave Velocity	The comparison between different measurement techniques with CSRR technique.
H. M. Teoh S. K. Yee, 2020 [13]	Dielectric Properties Characterization Based on Complementary Split-Ring Resonator	$\frac{\Delta f_r}{f_{r\_unloaded}} = \frac{\int_v^0 \Delta\varepsilon \mathbf{E}_1 \mathbf{E}_0 + \Delta\mu \mathbf{H}_1 \mathbf{H}_0 dv}{\int_v^0 \varepsilon_o \lvert \mathbf{E}_0 \rvert^2 + \mu_o \lvert \mathbf{H}_0 \rvert^2 dv}$

Sreedevi P. Chakyar, C. Bindu, Jolly Andrews and V. P. Joseph, 2017 [14]	Complex permittivity measurement using metamaterial split ring resonators	The lower the permittivity, then the higher the resonant frequencies.
Nutan Reddy, 2013 [16]	Split ring resonator and its evolved structures over the past decade	The width of split and the distance of gap affect resonant frequency.

CHAPTER 3

METHODOLOGY

3.1 Project Workflow

The general steps taken for the project workflow are shown as Figure 3.1.1. Firstly, the background research based on this title chosen should be carried out to identify the problems faced and objectives. There are some further investigations from reliable resources such as the knowledges on different types of sensing techniques, CSRR, dielectric properties of materials, etc. Next step is to design the project as well as to make decision for the planning on equipment required. It can help to smooth the progress and prevent the false perception as possible since an understanding about the method used in project has been gained. Subsequently, implementation of CSRR will be developed via CST Studio (software) and also fabrication (hardware). Testing, modification and simulation processes are repeated cyclically until obtaining the desired results. This is known as troubleshooting session which always be existed if the project's goal is not successfully accomplished. Last step is to analyze based on the performances presented in table or graph, then the project will be discussed and concluded at the end.

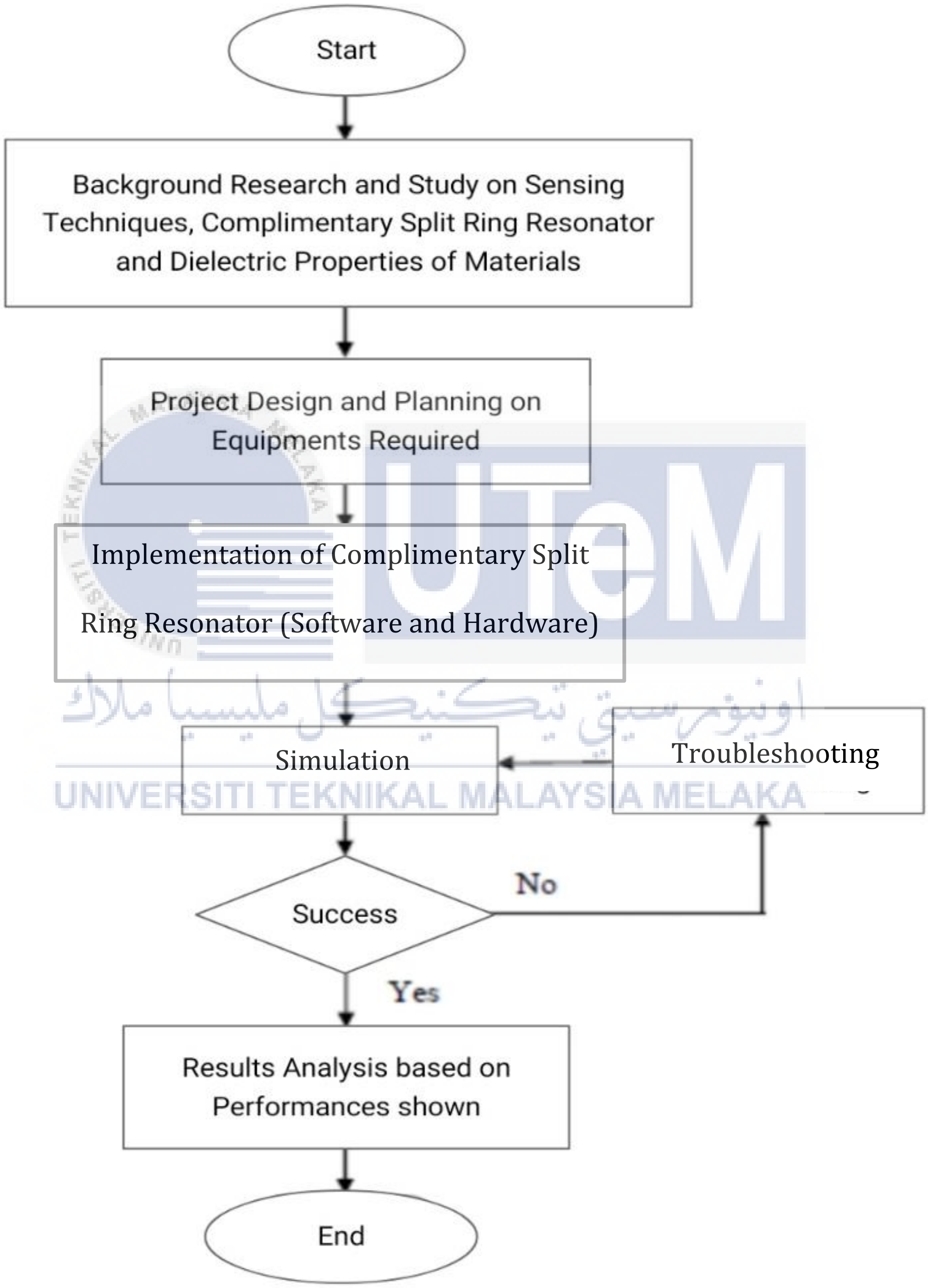

Figure 3.1.1: Flow Chart of Project

3.2 Software Implementation

For designing of complimentary split ring resonator via software, a software named as Computer Simulation Technology (CST) Studio Suite has been implemented. It offers a wide range of both general purposes and specialized solvers for electromagnetic (EM) and multiphysics problems in one user-friendly interface. Besides that, it also has a high-performance 3D EM software package for designing, analyzing and optimizing those EM components as well as system. Simulation enables the utilization of virtual prototyping so the risks of test failure can be minimized indirectly. Figure 3.2.1 represents its logo and various simulation tools inside CST.

Figure 3.2.1: Logo and its Simulation Tools

The proposed CSRR is designed with aid of CST software. The following Figure 3.2.2 illustrates about a few characteristics of proposed CSRR in this work. FR-4 with dielectric constant of 4.3, loss tangent of 0.02 and thickness of 15 mm has been applied as substrate. The width of the microstrip line is set at 1.83 mm to provide an impedance of 50 Ohms while the dimensions of CSRR etched on ground plane are listed as W = 0.6mm; S = 0.45mm; R_{out} = 4.65mm; G = 1mm. The formulas applied are as following that also have been discussed in the literature review part.

$$f_r = \frac{1}{2\pi\sqrt{LC}} \qquad \frac{\Delta f_r}{f_{r\_unloaded}} = \frac{\int_v^0 \Delta\varepsilon \mathbf{E}_1\mathbf{E}_0 + \Delta\mu \mathbf{H}_1\mathbf{H}_0 dv}{\int_v^0 \varepsilon_o |\mathbf{E}_0|^2 + \mu_o |\mathbf{H}_0|^2 \, dv}$$

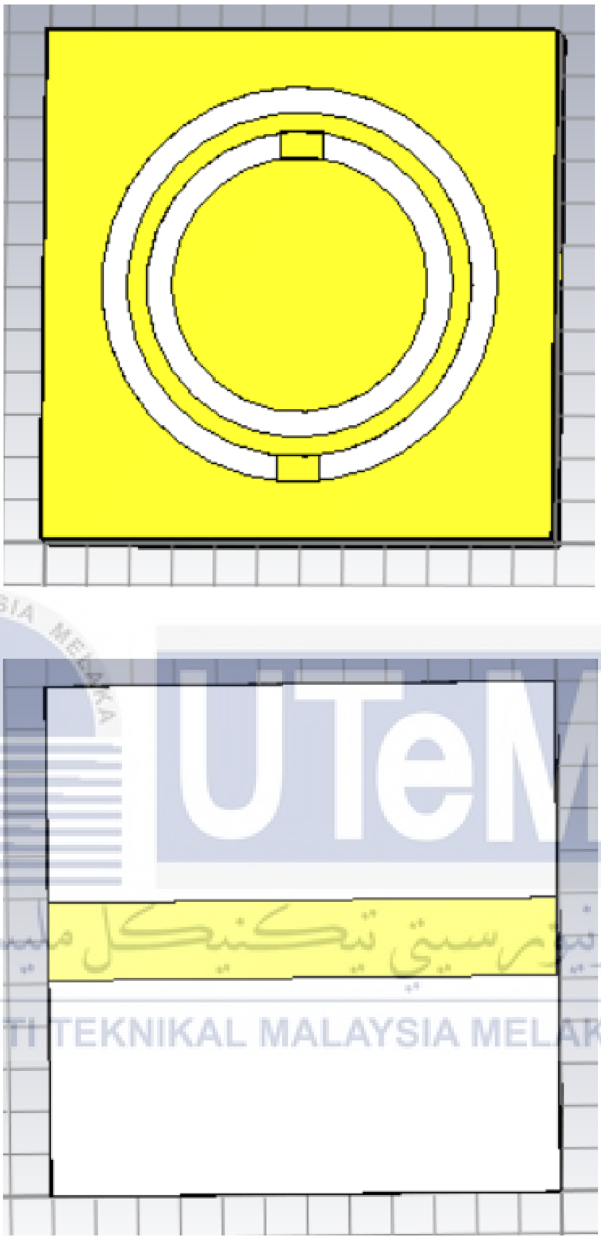

Figure 3.2.2: The Characteristics of Proposed CSRR

3.3 Hardware Implementation

For hardware implementation, it is very important to have the process of fabrication in order to produce a practical CSRR. The materials and components required should be prepared earlier in planning stage as Table 3.3.1. The price range for this project is within RM100. After that, the execution based on proposed design can be carried on in laboratory through process etching, soldering and so on. The outcome of model will be expected likely to Figure 3.3.1.

Table 3.3.1: The Functions of Materials/Components

Materials/Components	Functions (Price)
FR-4	Use for substrate (RM20)
Rogers RT5880	Use as MUT (RM20)
Rogers RO4350B	Use as MUT (RM20)
Rogers RO3010	Use as MUT (RM20)
2 SMA Connectors	Use for measurement system (RM10)

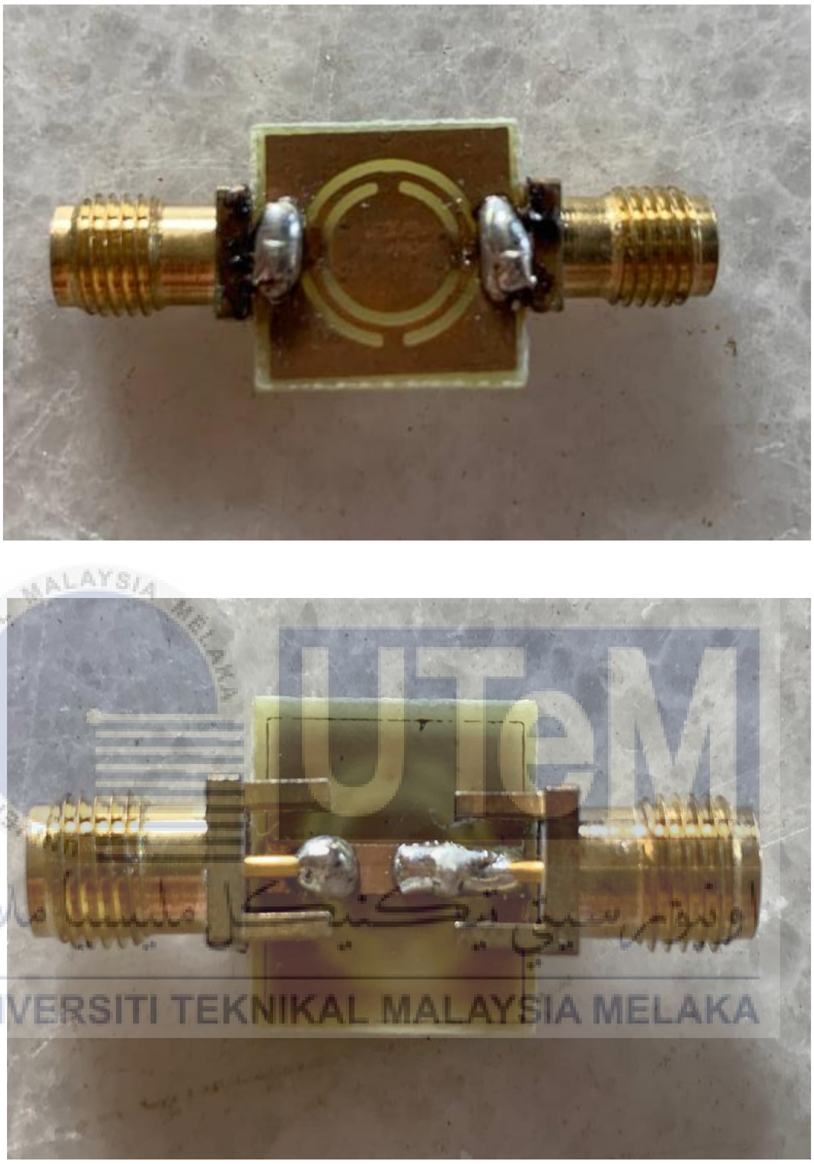

Figure 3.3.1: The Fabricated CSRR Model

3.4 CSRR Architecture

In this project, the CSRR architecture enables its resonant frequency operates at around 2.5GHz under unloaded condition. It will start from sensing until measuring for four types of MUT. For instance, Rogers RT5880, RO4350B and Rogers RO3010 with dielectric constant of 2.2, 3.66 and 11.2 respectively. These MUTs loaded on CSRR model can be sensed and also measured via SMA connectors soldered at both sides as Figure 3.3.2. The output results are performed in VNA at last. The relative change in resonant frequency will be affected which corresponding to relative change on permittivity of dielectric materials tested. The effects may relate with the sensitivity of CSRR. Figure 3.3.3 shows the measurement setup for this system.

Figure 3.3.2: MUTs Loaded on the CSRR for Measurement

Figure 3.3.3: Measurement System Setup

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Simulation of CSRR

The proposed CSRR has been simulated in CST software. Figure 4.1.1 shows the resonant frequency of CSRR under unloaded condition. The resonant frequency is 2.47GHz which around 2.5GHz.

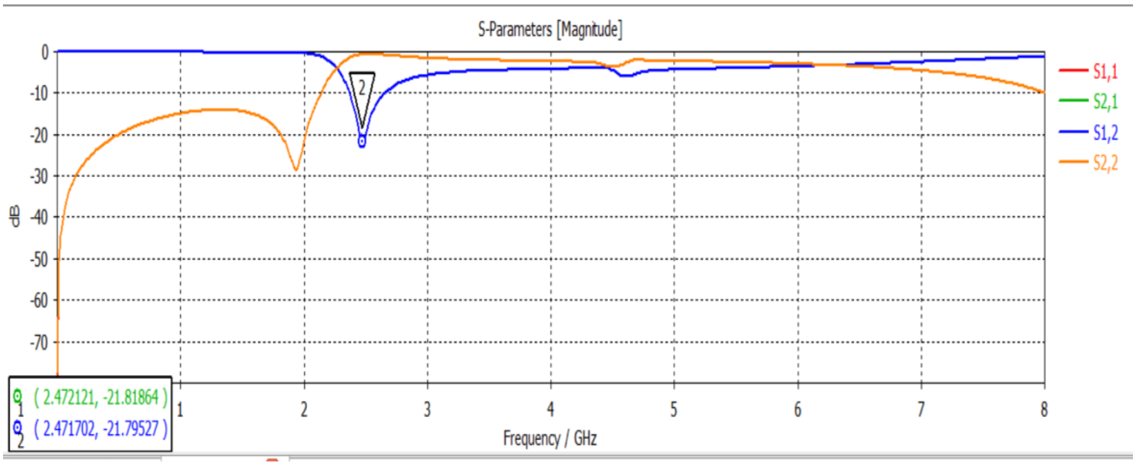

Figure 4.1.1: Resonant Frequency of CSRR in CST

There are some results about the simulation of different MUTs loaded on it.

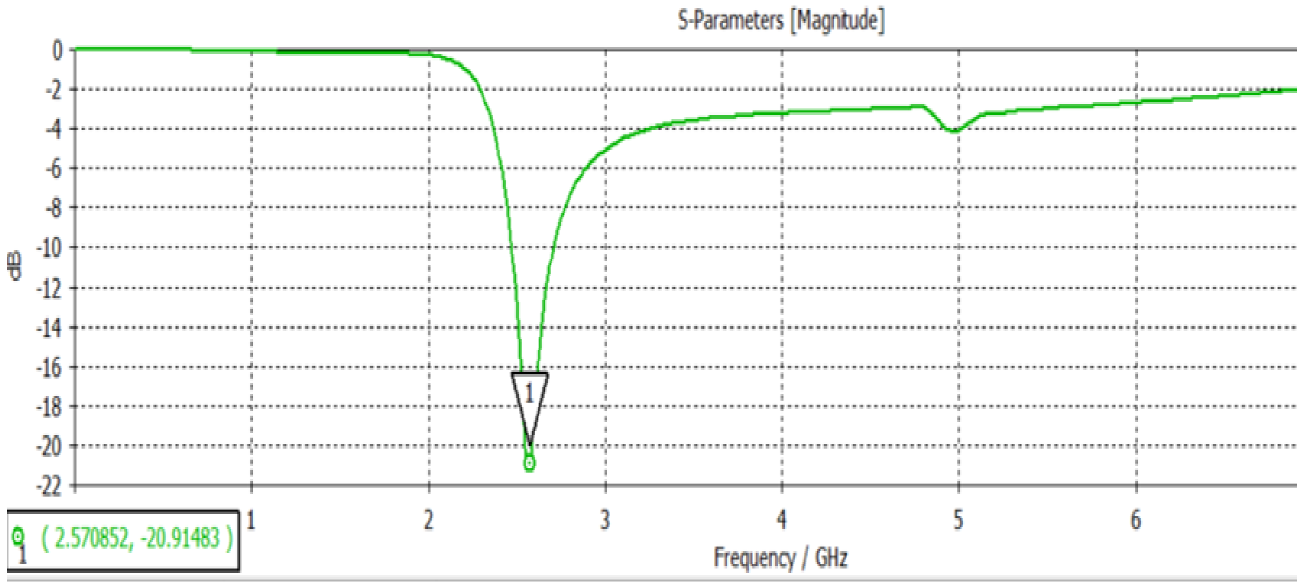

Figure 4.1.2: Simulation of Rogers RT5880 Loaded in CST

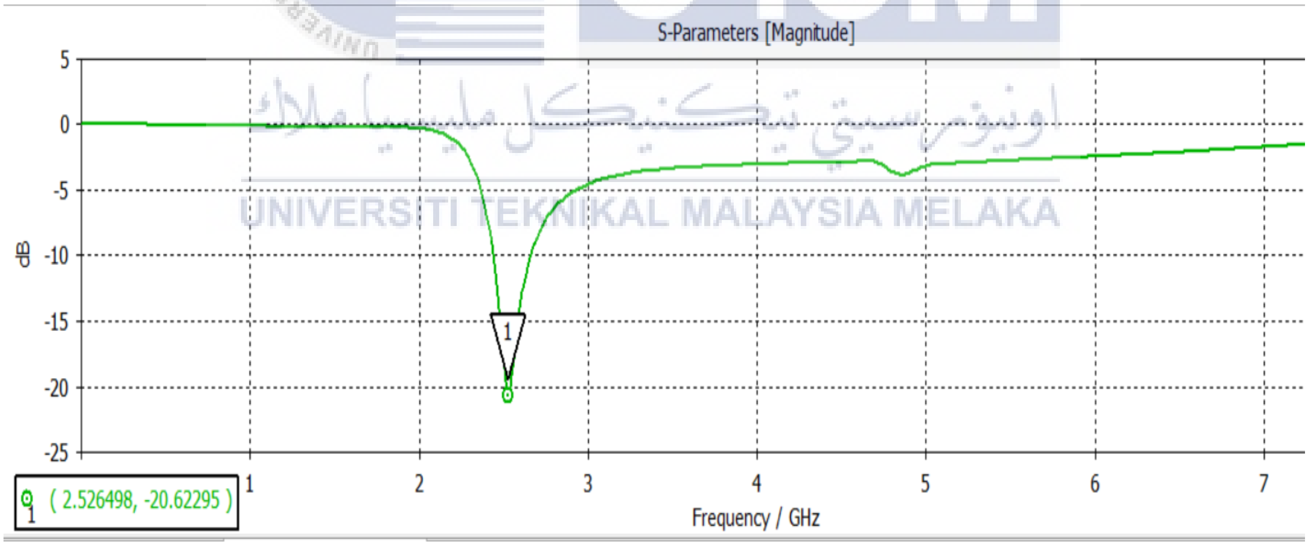

Figure 4.1.3: Simulation of Rogers RO4350B Loaded in CST

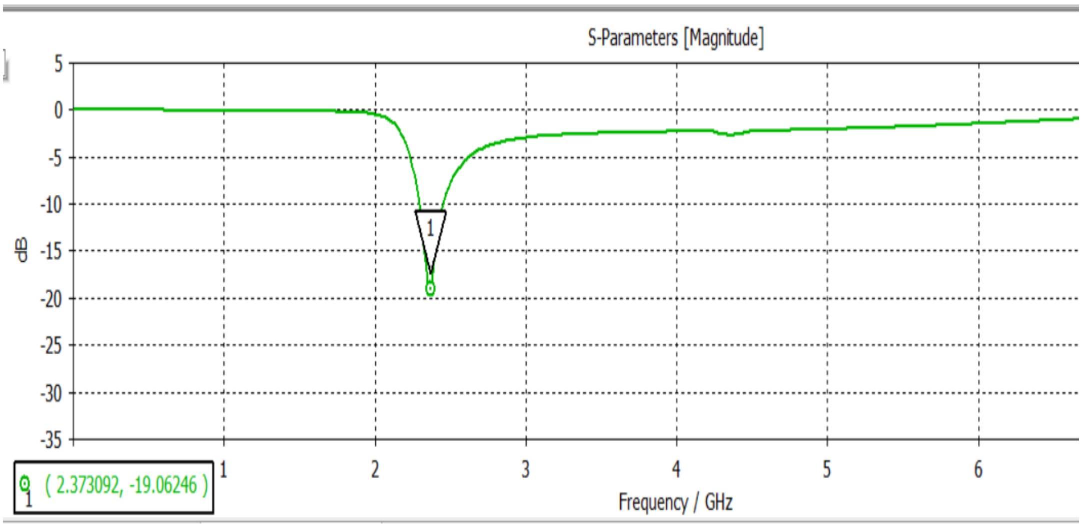

Figure 4.1.4: Simulation of Rogers RO3010 Loaded in CST

The proposed CSRR also has been developed in hardware which the results obtained show as following figures.

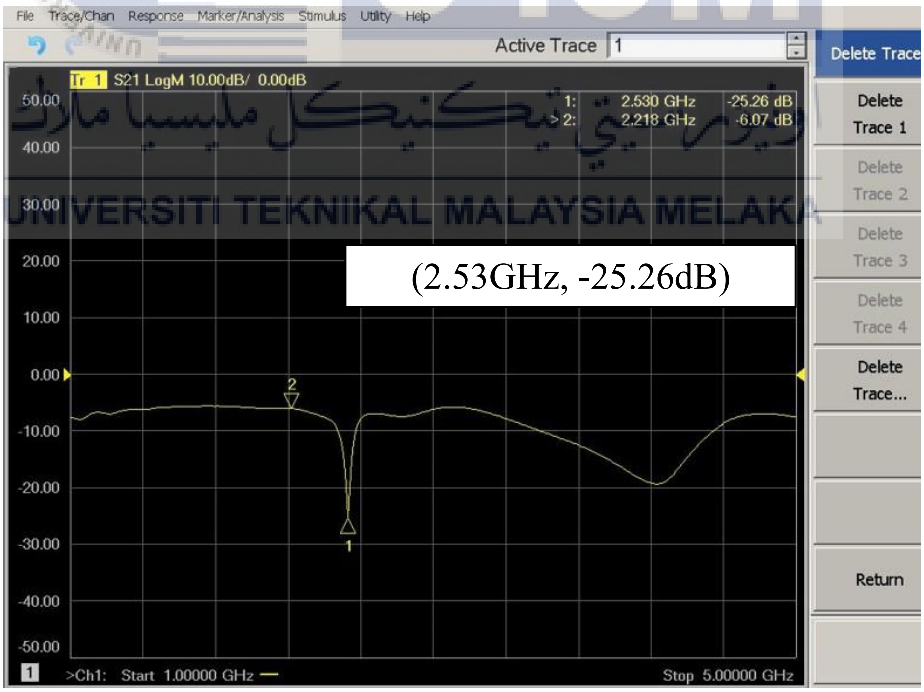

Figure 4.1.5: Resonant Frequency of CSRR in VNA

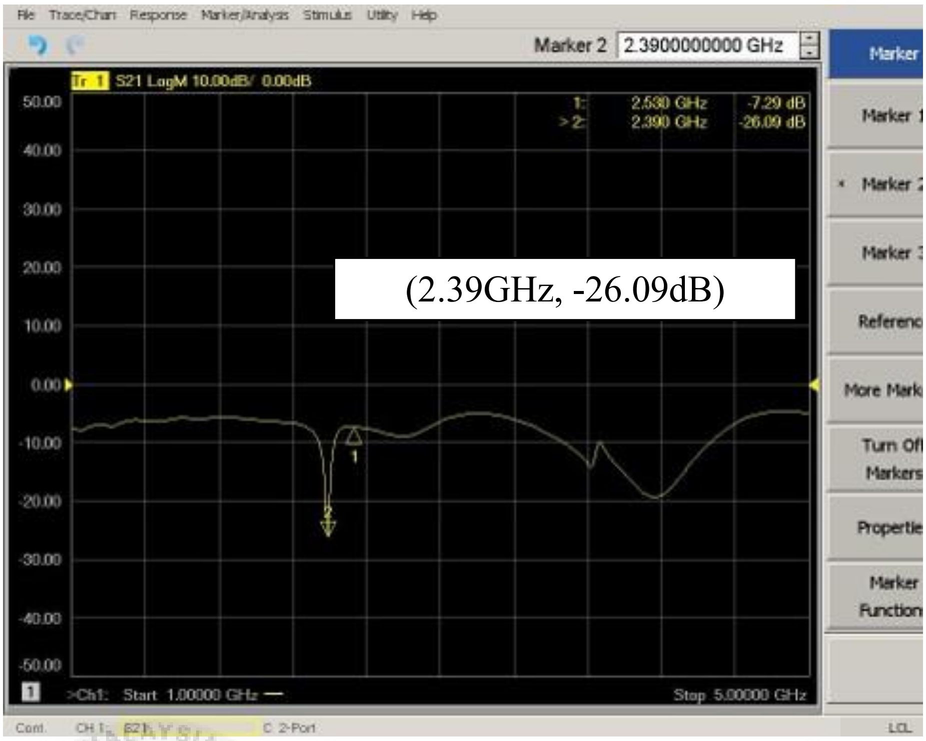

Figure 4.1.6: Simulation of Rogers RT5880 Loaded in VNA

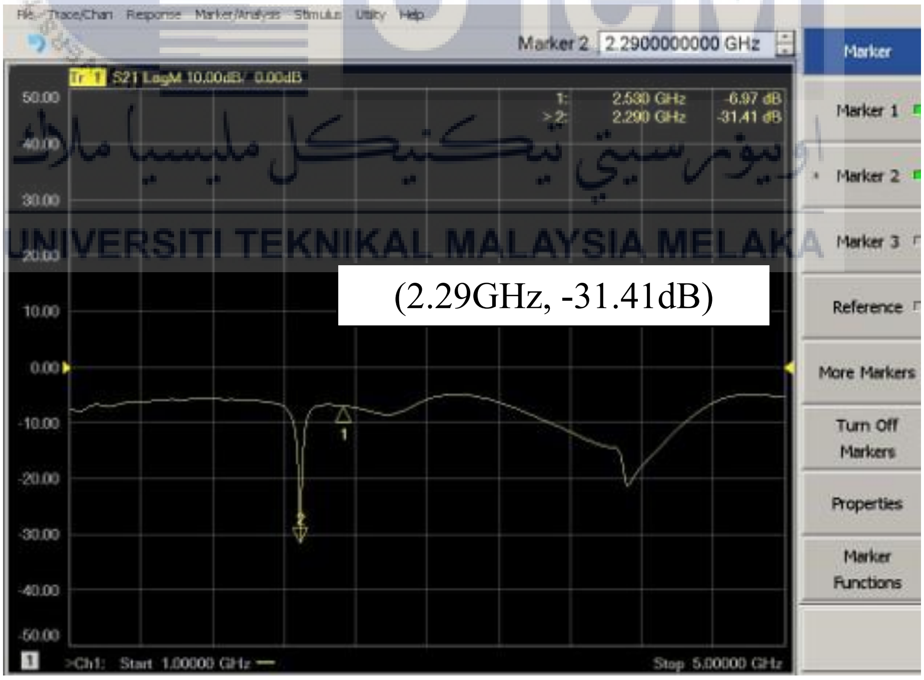

Figure 4.1.7: Simulation of Rogers RO4350B Loaded in VNA

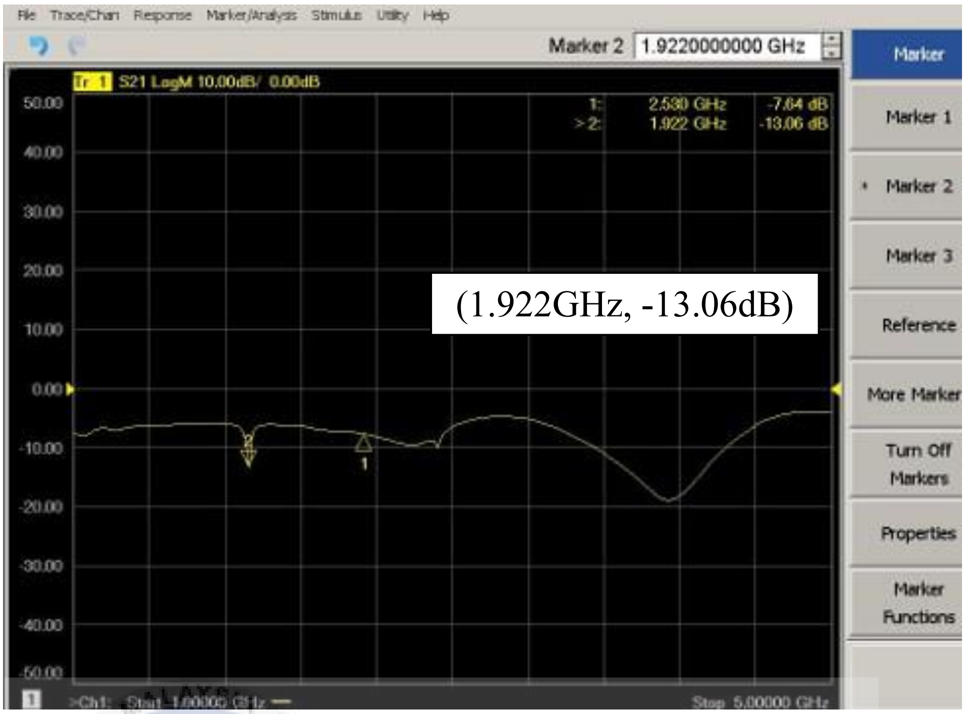

Figure 4.1.8: Simulation of Rogers RO3010 Loaded in VNA

Table 4.1.1: The Data Results of CSRR

Dielectric Constant of MUT	Simulation Values in CST Software	Measurement Values in CSRR Hardware
2.20	2.57	2.39
3.66	2.52	2.29
11.20	2.37	1.92

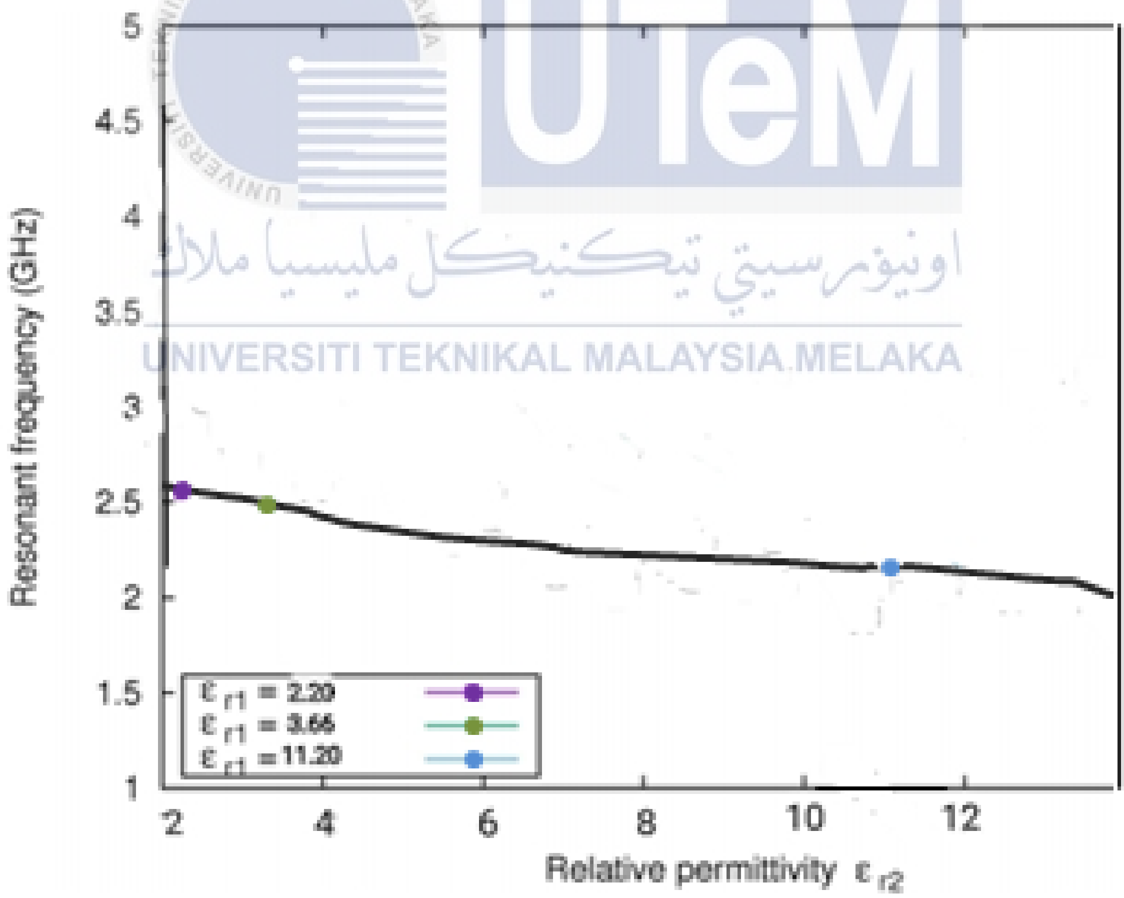

Figure 4.1.9: Relationship between Resonant Frequencies versus Relative Permittivity Values

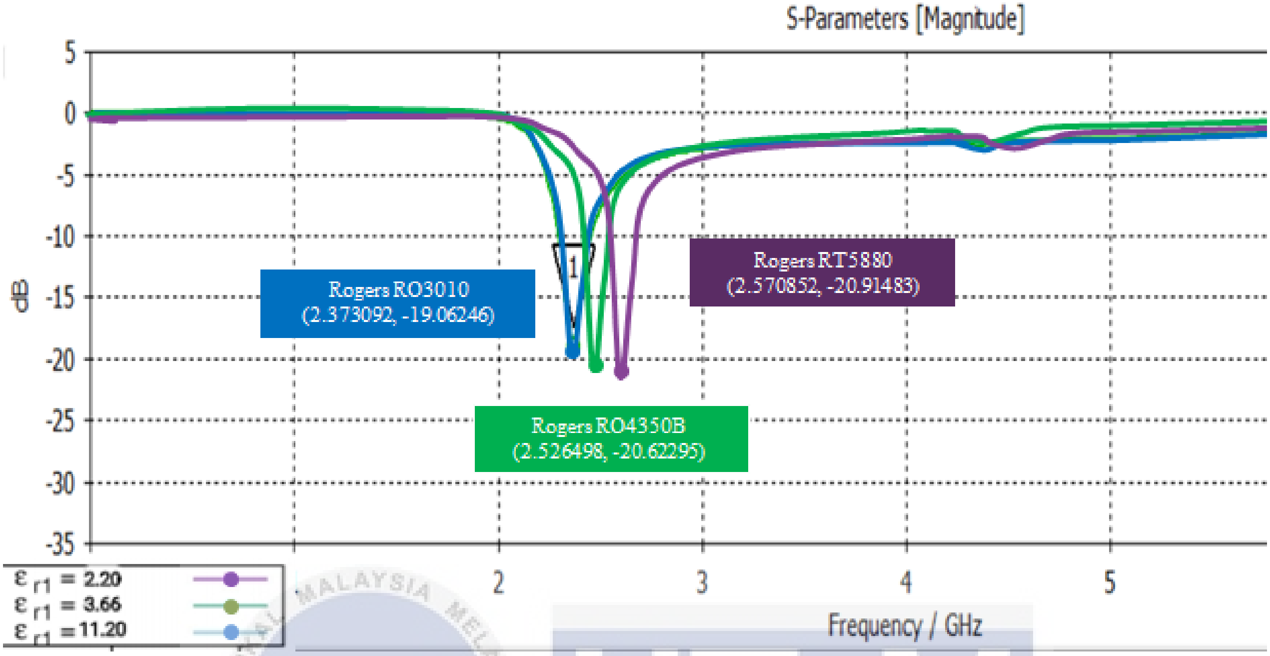

Figure 4.1.10: The Comparison of Results for Different MUTs Loaded on CSRR

4.2 Discussion

Those output graphs obtained in CST software for this proposed CSRR were considered quite ideal as what it should be achieved as the specific design was expected to allow the resonant frequency at 2.5GHz under unloaded condition which almost same as S-parameter S_{21} has been marked at 2.47GHz with -21.8dB that can be observed from Figure 4.1.1. The hardware of CSRR model was also gained around 2.53GHz with -28dB that can be accepted. S_{21} indicated its transmission coefficient while S_{11} indicated its reflection coefficient along the transmission system. In addition, electric field's distribution on ground plane was recognized as sensing area of MUT loaded for permittivity measurement. High intensity of electric field can be detected where was at the central of CSRR model so that MUT will be put on there for measurement. The width of the split and the distance of the gap also increased or decreased the resonant frequency. The increasing distance of gap then the increasing resonant frequency acquired. This was because its larger gap distance reduced the mutual capacitance of the equivalent circuit.

According to the research studied, the resonance frequency, f_r of CSRR will be shifted when the sensing area was exposed to various dielectric materials which consisting of different dielectric constant, ε_r. Figure 4.1.2 to Figure 4.1.4 proved it convincingly by performing those reasonable results above. The rank began with Rogers RT5880, RO4350B then ended up with Rogers RO3010 in descending order of resonant frequency shifted as 2.57GHz, 2.53GHz and 2.37GHz respectively. The simulation was matched since permittivity values as 2.2, 3.66 and 11.2 corresponding to the order. This statement has been explained that the higher the permittivity of tested dielectric material, then the lower the frequency shifted will be occurred in Figure 4.1.9 and Figure 4.1.10.

The hardware implementation and measurement also has been carried out during progress of project. The results were obtained as Figure 4.1.5 until Figure 4.1.8 shown above from VNA. Although those results were slightly different when compared to the simulation of CSRR model in CST but it also proved that the relationship between the permittivity of MUT and resonant frequency as theory as the higher the permittivity of tested dielectric material, then the lower the frequency shifted in Figure 4.1.9 and Figure 4.1.10. This was due to the reduction of space charge polarization effect. The differences in results may due to the undefined errors in the MUT or the noise disturbed during measurement.

CHAPTER 5

CONCLUSION AND FUTURE WORKS

5.1 Significances of Project

This sensing technique by CSRR gains the high sensitivity and accuracy measurements of dielectric materials characterization in a way of low cost, compact in size and simplicity when compared to other conventional sensing techniques. It helps to avoid wasting in resources as well as save time due to the precise measurements can be made for different dielectric properties of materials chosen. Therefore, it is sustainable and environmental friendly. The project has been implemented in software and also hardware for analysis. A relationship between the resonant frequency and permittivity properties of dielectric materials is proven that the higher the permittivity of tested dielectric material, then the lower the resonant frequency shifted. The objectives have been achieved and project is accomplished successfully at the end.

For future works, the microwave resonator can be improved by applying wireless-based technology. It can be embedded with LAN technology so that changing in frequencies according to different circumstances since microwave resonator has the characteristics of storing energy and selecting frequency. Its operation will not be a wide range of deviation. Thus, the target of more energy saving can be easily achieved. At the same time, it will become more sustainable which make more users or industries to utilize widely.

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APPENDICES

Material	Average Dk
RO3003™	3.00
RO3006™	6.40
RO3010™	11.04
RO3035™	3.59
RO3203™	2.99
RO3206™	6.27
RO3210™	10.80
RO3730™	3.01
RT/duroid® 6002	2.94
RT/duroid 6006	6.32
RT/duroid 6010	10.56
RT/duroid 6202	2.94
RT/duroid 5870	2.33
RT/duroid 5880	2.21
RT/duroid 5880LZ	1.99
TMM®3	3.39
TMM4	4.57
TMM6	6.02
TMM10	9.56
TMM10i	10.16
RO4350B™	3.66
RO4360™	6.60
RO4450B™ 4.0mil	3.9
RO4450B 3.6mil	3.7
RO4450F™	3.9

Appendix 1: Dielectric Constant of Various Materials

H. PERANCANGAN PROJEK
PROJECT PLANNING (GANTT CHART)

Senaraikan aktiviti-aktiviti yang berkaitan bagi projek yang dicadangkan dan nyatakan jangka masa yang diperlukan bagi setiap aktiviti.
List all the relevant activities of the proposed project and mark the period of time that is needed for each of the activities.

	SEM I																			SEM BREAK					SEM II															
Aktiviti Projek *Project Activities*	1	2	3	4	5	6	7	8	9	1	1	1	1	1	1	1	1	1	1	2	2	2	2	2	1	2	3	4	5	6	7	8	9	1	1	1	1	1 4	1 5	1 6
1) Project Briefing and Title Registration	X										SEMINAR PSM I																											SEMINAR PSM II		
2) Background Research and Study		X	X	X																																				
3) Proposal Preparation, Defense and Submission			X	X																																				
4) Thesis Writing for Introduction and Literature Review, Methodology					X	X	X	X	X	X		X								X	X	X	X																	
5) Software Implementation								X	X	X		X	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X												
6) Thesis Draft Submission												X	X	X																			X	X	X	X	X			
7) Hardware Implementation																											X	X	X	X	X	X	X	X						
8) Thesis Writing for Results & Conclusion, Recommendation & Future Work and Abstract																						X	X	X	X	X	X	X					X	X	X	X	X			
9) Project Finalization																																	X	X	X	X	X			

Appendix 2: Gantt Chart of Project