UNIVERSITI TEKNIKAL MALAYSIA MELAKA

Faculty of Electronics and Computer Technology and Engineering

DEVELOPMENT OF DIELECTRIC PROPERTIES MEASUREMENT SYSTEM USING DUAL ENDED WAVEGUIDE

MOSES A/L FRANCIS

Bachelor of Electronics Engineering Technology (Telecommunications) with Honours

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DEVELOPMENT OF DIELECTRIC PROPERTIES MEASUREMENT SYSTEM USING DUAL ENDED WAVEGUIDE

MOSES A/L FRANCIS

A project report submitted
in partial fulfilment of the requirements for the degree of
Bachelor of Electronics Engineering Technology (Telecommunications) with Honours

Faculty of Electronics and Computer Technology and Engineering

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2024

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DEDICATION

First and far most, I would like to thank god in humble acknowledgment of the divine knowledge that lights my path, I dedicate the efforts in the back of this record to the Almighty. May the knowledge received and shared reflect a dedication to greater values and a purposeful existence guided by means of faith. Secondly, I would like to thank my family whose love and encouragement are the cornerstones of my endeavours. Your unwavering assist empowers me to reach new heights, and this file is a testimony to the values instilled in me via our shared experiences. Furthermore, To my friends, the kindred spirits who add shade to the canvas of my life. Through laughter, shared challenges, and shared triumphs, they deliver richness to my journey. This report is committed to the camaraderie that fuels our collective growth.

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ABSTRACT

In this thesis, The type of project done is based on waveguide. The frequency range of the waveguide is by using X-band frequency which is from (8-12GHz). The waveguide is fabricated by using an aluminum block. There is an equipment tool which is called a dielectric probe, which is used to measure dielectric substances. It comprises a sensor that contacts the substance and generates an electric field to assess its reaction. The material or properties that are measured are by using 2 types, which are FR-4 and Rogers 5800. The waveguide that has been proposed is used to measure the dielectric properties. Many tools work as the dielectric probe, even our university they got this tool, but the catch is that the dielectric probe, is easily broken and also it is costly. To prevent breakage, it needs to be handled and stored carefully. Dielectric probe prices can also change based on the characteristics and capacities of a particular model. Pricier models typically have more precision and capability. In this case, This is the main problem that we face and we cannot be spending too much money on a piece of equipment that can be broken easily. In this paper, with the help of my supervisor, a proposed low-cost system to measure dielectric probes has been mentioned. There will be two types of measurements: in simulation using CST software and measurement in real-time. The results are taken from simulation and measurement and compared between them. This comparison is made by using simulation to prove whether the equipment that is fabricated measures the dielectric properties correctly or not.

ABSTRAK

Dalam tesis ini, Jenis projek yang dilakukan adalah berdasarkan pandu gelombang. Julat frekuensi pandu gelombang adalah dengan menggunakan frekuensi jalur X iaitu dari (8-12GHz). Pandu gelombang dibuat dengan menggunakan blok aluminium. Terdapat alat peralatan yang dipanggil probe dielektrik, yang digunakan untuk mengukur bahan dielektrik. Ia terdiri daripada sensor yang menghubungi bahan dan menghasilkan medan elektrik untuk menilai tindak balasnya. Bahan atau sifat yang diukur adalah dengan menggunakan 2 jenis iaitu FR-4 dan Rogers 5800. Pandu gelombang yang telah dicadangkan digunakan untuk mengukur sifat dielektrik. Banyak alat berfungsi sebagai probe dielektrik, walaupun universiti kami mereka mendapat alat ini, tetapi tangkapannya ialah probe dielektrik, mudah pecah dan juga mahal. Untuk mengelakkan kerosakan, ia perlu dikendalikan dan disimpan dengan berhati-hati. Harga probe dielektrik juga boleh berubah berdasarkan ciri dan kapasiti model tertentu. Model yang lebih mahal biasanya mempunyai lebih ketepatan dan keupayaan. Dalam kes ini, Ini adalah masalah utama yang kita hadapi dan kita tidak boleh membelanjakan terlalu banyak wang untuk peralatan yang boleh dipecahkan dengan mudah. Dalam kertas kerja ini, dengan bantuan penyelia saya, cadangan sistem kos rendah untuk mengukur probe dielektrik telah disebutkan. Terdapat dua jenis pengukuran: dalam simulasi menggunakan perisian CST dan pengukuran dalam masa nyata. Keputusan diambil daripada simulasi dan pengukuran dan dibandingkan di antara mereka. Perbandingan ini dibuat dengan menggunakan simulasi untuk membuktikan sama ada peralatan yang difabrikasi mengukur sifat dielektrik dengan betul atau tidak.

ACKNOWLEDGEMENTS

I would like to express my heartfelt understanding to my thesis supervisor, Dr.Muhammad Inam Abbasi for his unwavering support, guidance, and information all through this research journey. His priceless comments has notably enriched the pleasant of my work. I am additionally grateful to my household and buddies for their unwavering encouragement and perception throughout the challenges of this educational pursuit. The help of my peers, colleagues, and the University Teknikal Malaysia Melaka, (UTeM) community has been instrumental in shaping the consequence of this thesis. Together, their contributions have made this educational fulfilment possible, and for that, I am truly thankful.

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LIST OF SYMBOLS

λ - Lambda
ε - Epsilon
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-
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LIST OF ABBREVIATIONS

f - Frequency
c - Speed of light
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CHAPTER 1

INTRODUCTION

1.1 Background

A dielectric probe is a tool utilized for gauging the electrical features of various materials. This device is made up of electrodes enclosed by a dielectric substance. It serves a wide range of purposes, including moisture content measurement, material characterization, process control, non-destructive testing, and medical diagnostics. Dielectric probes help identify the dielectric properties of materials, offering crucial insights into their composition and electrical functioning.

1.2 Addressing Global and Societal Issue

In many businesses and scientific disciplines, dielectric probes are complex instruments that are used to measure the dielectric characteristics of materials that have become essential tools. Although these probes might not directly address societal or global problems, their applications and ramifications could have significant effects. The impact on the environment, food security and safety, material characterization, energy efficiency, health and biomedical applications, accessibility, and affordability are highlighted in this part as it examines the relationship between dielectric probes and bigger issues facing our global civilization.

To begin with, for the impact on the environment, dielectric probes are used in a variety of fields, including material science and agriculture. Even though these applications provide essential insights for process and quality control optimization, it is crucial to address any environmental issues related to these businesses. Issues including excessive energy use, waste production, and the use of dangerous chemicals need to be carefully considered. The environmental effect of these businesses can be reduced by using dielectric probe technology responsibly, consuming less energy, adopting sustainable practices, and producing less trash [1].

For safety and security, dielectric probes are essential for determining moisture content, maturity, and quality in the food production industry. A global issue that directly affects the health and well-being of the general public is the significance of food safety and security. Dielectric probes help to overcome these issues by enabling accurate food quality monitoring and control across the supply chain. Their usage in limiting microbial development, deterioration, and contamination improves food safety protocols, protecting people's health and guaranteeing a reliable food supply for populations around the world [2].

Material characterization and energy efficiency are also important. In material science and engineering, the use of probes to explore dielectric behavior has significant specifications. For the creation of cutting-edge technology, such as electronic devices, energy storage systems, and renewable energy sources, it is crucial to comprehend the electrical properties of various materials. Dielectric probes help accelerate the development of more eco-friendly and energy-efficient devices by improving material characterization. This in turn tackles issues such as resource depletion, climate change, and the need for sustainable energy options [3].

Furthermore, The measuring of tissue characteristics for diagnostic and therapeutic reasons is made possible by the use of dielectric probes in health and biomedical applications. Dielectric probes, for instance, show promise in the measurement of tissue electrical characteristics and hydration levels for medical imaging, cancer detection, and therapy planning. However, it's important to pay close attention to ethical issues, patient privacy, and appropriate technology use. It is essential to strike a balance between technology development and societal well-being to exploit the advantages of dielectric probes while upholding patient rights and fostering ethical healthcare practices [4].

In summary, The widespread usage of dielectric probes offers a chance to address societal and global problems conscientiously and ethically. Dielectric probes can promote progress by reducing environmental impact, boosting food safety and security, promoting energy efficiency, and advancing biomedical research. We must take a comprehensive approach to using new technologies, taking into account how they may affect society, the environment, and accessibility. Dielectric probes have a critical role to play in addressing global issues and promoting sustainable development when used responsibly.

1.3 Problem Statement

In these current times, the dielectric probes are quite fragile and require careful handling to avoid breakage. If the equipment breaks, it becomes impossible to measure the dielectric substrates. Additionally, the excessive price of purchasing these tools is a massive concern for universities. To tackle this challenge, my supervisor and I devised an answer to improve a dielectric probe with the usage of a dual-ended waveguide. This alternative is nearly comparable to the dielectric probe however is much less expensive.

1.4 Project Objective

The main aim of this project is to make a dielectric probe which costs less. Specifically, the objectives are as follows:

a) To develop a technique for the simulation and data collection for a dual wave guide dielectric measuring system.

b) To build a robust and low-cost dual waveguide dielectric measuring system in the X-band frequency range (8 GHz to 12 GHz).

c) To characterize the performance of the system by measuring the dielectric properties of different substrates.

1.5 Scope of Project

The scope of this project are as follows:

a) The system consists of a dual ended waveguide which uses a 2-port Vector Network Analyzer.

b) The simulation of the proposed waveguide technique is done using CST studio suite. The testing is done in the MRG lab.

c) The maximum range of frequency range that can be measured in the equipment is (8 GHZ to 12 GHz).

d) There are multiple results from simulations and measurements from the type of dielectric substrates used which is FR-4 and Rogers 5800.

1.6 Summary

The essay introduces the magnitude of dielectric probes, highlighting their various functions in measuring the electrical points of materials. It emphasizes the potential have an impact on of dielectric probe science on international issues such as environmental sustainability, food safety, energy efficiency, and healthcare. The essay then addresses a unique problem related to the fragility and cost of cutting-edge dielectric probes and proposes a answer the usage of a dual-ended waveguide. Project goals consist of creating a reasonable and durable dielectric probe. The scope involves utilizing a dual-ended waveguide with a 2-port Vector Network Analyzer, simulation, testing, and measuring dielectric homes in the frequency vary of 8 GHz to 12 GHz. Overall, the task pursuits to contribute responsibly to addressing international challenges via technological innovation.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This literature review is concentrate on the history, specifics, and theories regarding my project. Rather than delving into the broader subject of dielectric properties, which includes the study of materials and their electrical behaviour, characterization of dielectric materials, and the use of dielectric materials in various fields. Pertinent and significant research papers, journals, publications, and other sources, including earlier efforts using similar technology and approaches, is investigated to gather vital knowledge and insights. The main focus of this literature review chapter is to highlight an efficient and dependable dielectric probe that can be utilized by everyone.

Furthermore, Chapter 2, summarizes all the data collected, including previous dissertations and other important resources. This chapter is compile and discuss all relevant issues related to the development of dielectric probes to obtain the correct measurements for dielectric substrates.

2.2 The History of Dielectric Properties

Dielectric properties refer to the behaviour of substances when uncovered to electric fields. The history of grasp dielectric houses are carefully tied to the development of electrical energy and the exploration of how distinctive substances respond to electric fields. Here's a short overview of the papers. First of all in early observations, from the 18th century, scientists like Benjamin Franklin began experimenting with electrical energy and mentioned that positive materials, such as glass and rubber, should keep an electric-powered charge. These observations laid the foundation for similar exploration [5].

Dielectric constant in the early nineteenth century, carl Fredrich gauss added the thinking of the dielectric constant. He determined that inserting a dielectric cloth between the plates of a capacitor extended its capacitance. The dielectric steady quantifies a material's capability to keep electrical strength compared to a vacuum , Maxwell's equations on the other hand in the mid-19th century, James Clerk Maxwell developed a comprehensive idea of electromagnetism. His equations mathematically described the relationship between electric-powered and magnetic fields, incorporating the conduct of dielectric materials. Maxwell's work supplied a theoretical framework for understanding the interplay between electric-powered fields and dielectrics [6].

Furthermore, Dielectric breakdown later in the 19th century, researchers focused on the dielectric breakdown, which takes place when an insulating fabric loses its insulating properties and allows electrical modern-day to flow. This investigation led to the improvement of increased insulation substances with greater dielectric strengths, such as ceramics and artificial polymers [7].

Dielectric relaxation in the early 20th century, scientists discovered dielectric relaxation, a phenomenon the place the dielectric houses of substances alternate over time when uncovered to alternating electric powered fields. This conduct arises from the reorientation of polar molecules inside the material. Dielectric rest is fundamental for various applications, such as capacitors and dielectric spectroscopy [8].

Modern advancements in the latter one and a half of the 20th century and beyond, good sized progress has been made in characterizing dielectric properties. Advanced methods like dielectric spectroscopy, impedance spectroscopy, and time-domain reflectometry have enabled precise measurements across a broad vary of frequencies and temperatures. These advancements have facilitated the graph and optimization of dielectric substances for applications in electronics, telecommunications, power storage, and medical diagnostics. The appreciation of dielectric properties has advanced thru scientific exploration, experimentation, and the development of theoretical frameworks. This growth has deepened our expertise of how materials interact with electric fields and paved the way for numerous practical purposes [9].

2.3 Usage of Dielectric Homes to dielctric subtrates

Dielectric homes play a vital role in the design and software of dielectric substrates. Dielectric substrates are materials with excessive electrical insulation properties that are used in a number of electronic and conversation devices, such as printed circuit boards (PCBs), antennas, microwave circuits, and built-in circuits. The dielectric houses of these substrates, including dielectric constant, loss tangent, and frequency response, have a giant effect on the overall performance of these devices [10].

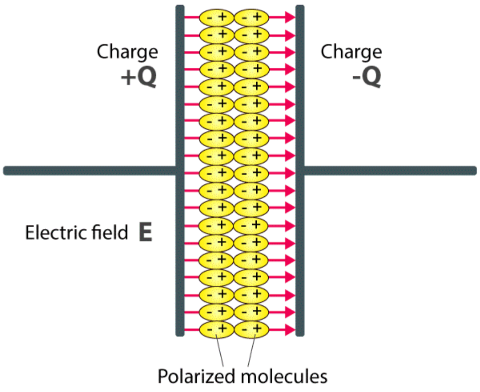


Figure 2.1 Dielectric Properties

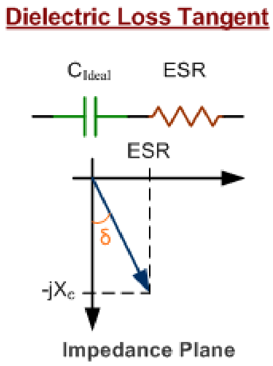


Figure 2.2 Dielectric Loss Tangent

In signal transmission and impedance controls, a dielectric substrate with a precise dielectric constant is used to control the characteristic impedance of the transmission line on the PCB. By deciding on substrates with gorgeous dielectric properties, designers can gain specific impedance matching for high-speed digital alerts and minimize reflections and signal loss. Then in high-frequency attenuation and operation, dielectric substrates with high dielectric constant permit the attenuation of electronic elements and circuits. They enable smaller feature sizes and decreased parasitic capacitance, making it easier to format compact devices. Additionally, low dielectric loss tangent substrates are preferred for high-frequency purposes to limit signal attenuation and maintain signal integrity [11].

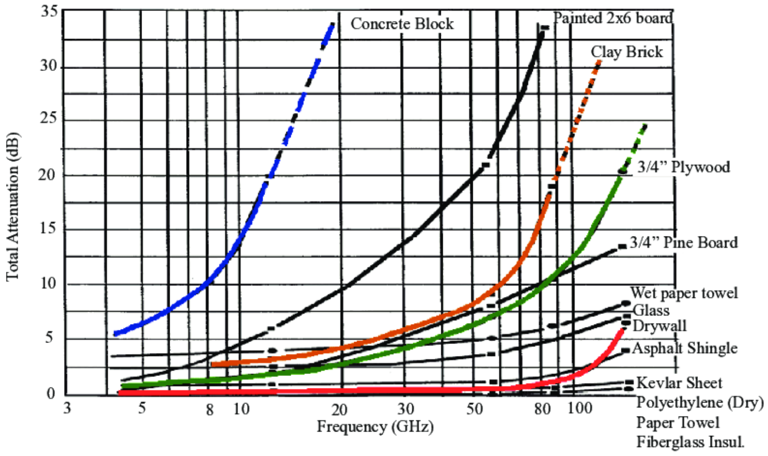


Figure 2.3 Attenuation vs Frequency graph

Next, in Antenna designs, dielectric substrates are often used in antenna construction. The dielectric regularity of the substrate influences the radiation pattern, gain, and bandwidth of the antenna. Low dielectric constant substrates are frequently used for broadband applications, while high dielectric consistent substrates are suitable for reaching compact antenna designs. Moving on to microwave circuits, dielectric substrates are widely used in microwave circuits, such as filters, couplers, and resonators. The dielectric residences of the substrate affect the overall performance of this circuit, together with its frequency response, power managing capability, and fine element (q factor) [12].

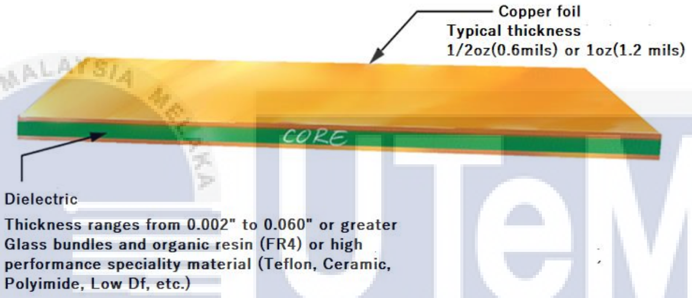


Figure 2.4 Dielectric Substrate

Furthermore, In Thermal management, dielectric substrates with true thermal conductivity are used for thermal administration purposes. This substrate helps dissipate warmness generated utilizing electronic components, making sure environment-friendly cooling and stopping overheating. It is important to word that the preference for dielectric substrate depends on specific application requirements such as frequency range, power handling, measurement limitations, and thermal considerations. Designers carefully consider the dielectric properties of the substrate to obtain ultimate performance and reliability in electronic circuits and devices [13].

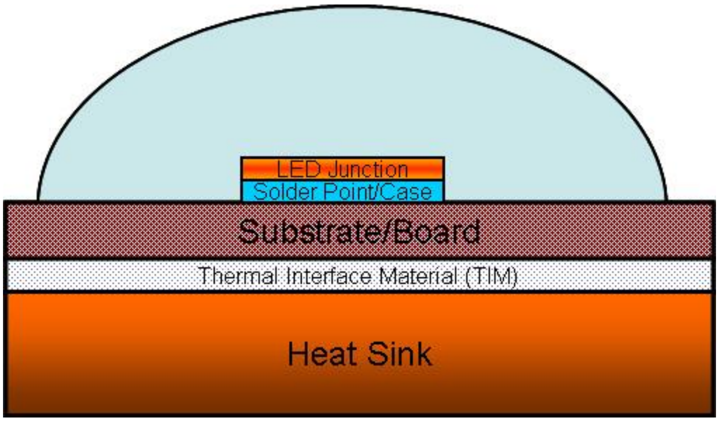


Figure 2.5 Dielectric Substrate using Thermal Material

2.4 Related Previous Project

2.4.1 Open-ended coaxial probes used to gather dielectric properties of biological tissues

In the year 2022, Maenhout G, published an article on how to evaluate the dielectric characteristics of biological tissues by using an open-ended coaxial probes. These probes are made of a dielectric substance sandwiched between an inner and an outer conductor. Researchers can learn about tissue composition, shape, and physiological state by sending an electromagnetic signal via the probe and examining the ensuing electrical properties, such as permittivity and conductivity. Applications including tissue characterization, imaging, and monitoring are crucial in areas like cancer detection and surgical planning [14].

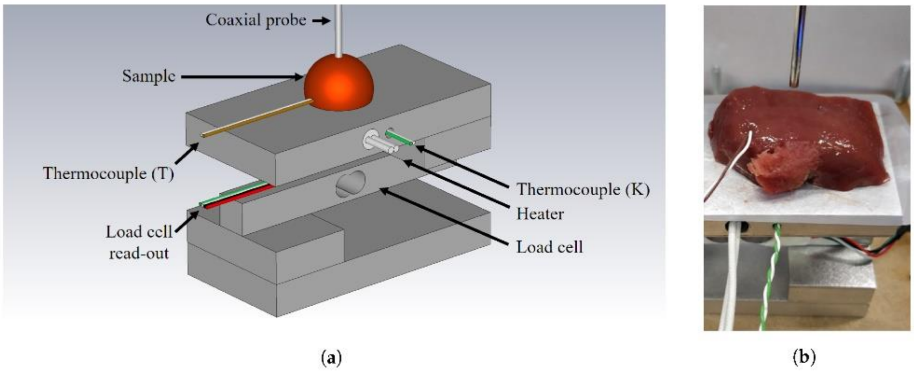


Figure 2.6 Dielectric measurement of biological tissues

2.4.2 Transmission Phase-Shift Method for Complex Permittivity Determination of Biological Sample Performed Using X-Band Rectangular Waveguide

In the year 2020, Effendi M,Putra Prastio , published a paper on The transmission phase-shift method which is a method that is for figuring out the complicated permittivity of a biological sample using an X-band rectangular waveguide. The approach determines the dielectric characteristics of the sample by calculating the phase shift of the transmitted signal in comparison to a reference signal. In disciplines including biomedical engineering, agriculture, and food science, it is frequently employed in microwave and millimetre-wave measurements for characterizing materials, including biological samples [15].

Figure 2.7 Measurement setup using an X-band rectangular waveguide

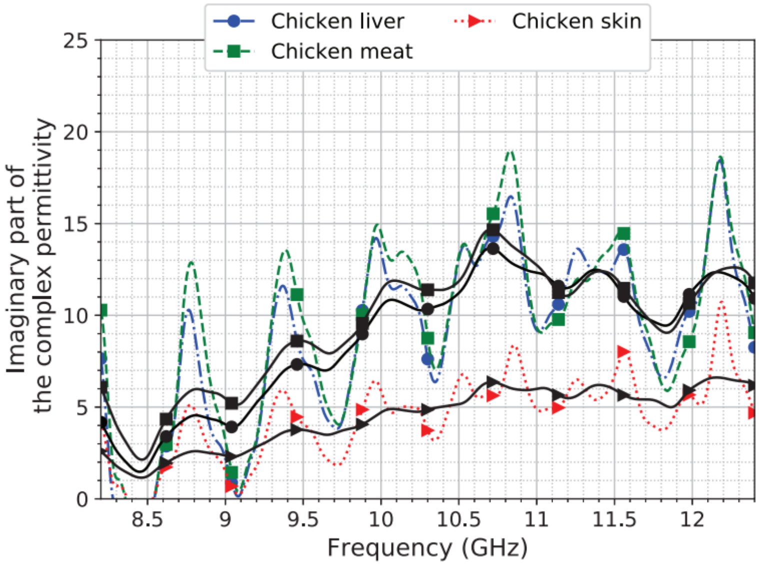


Figure 2.8 Real part of complex permittivity for some biological samples

2.4.3 Dielectric Properties of Common Building Materials for Ultrawideband Propagation Studies

In the year 2020, Zhekov S, Franek, published an article on dielectric properties of common building materials for Ultrawideband. In this article two open-ended coaxial probes are used to measure the dielectric characteristics. Since most materials adhere to it, the single-pole Cole-Cole model is used to fit the measured data. Additionally, fitting parameters for the multipole Debye model, which can be used in place of the Cole-Cole model and is better suited for FDTD applications, are provided. As a result, there is a simple method for getting the data, which is useful when wideband propagation is taken into account. This article reported the average measurement of the complicated relative permittivity of several building materials. A open-ended coaxial-probe test system was used to conduct the measurements across the frequency range of 0.2-67 GHz [16].

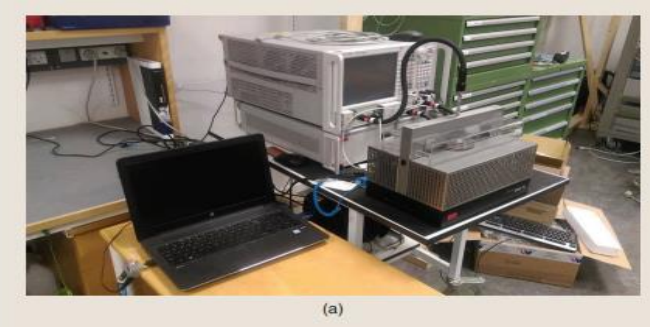


Figure 2.9 (a) The measurement system

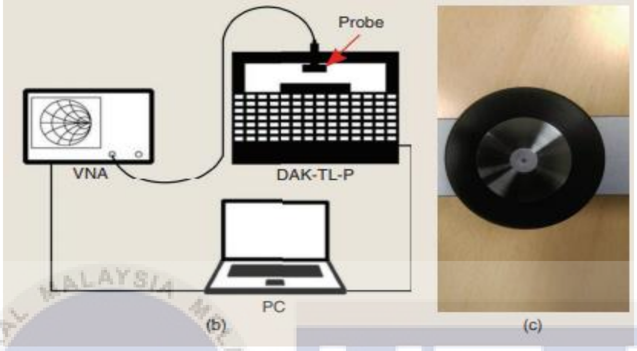


Figure 2.10 (b) a block diagram of the measurement system, and (c) the HF probe

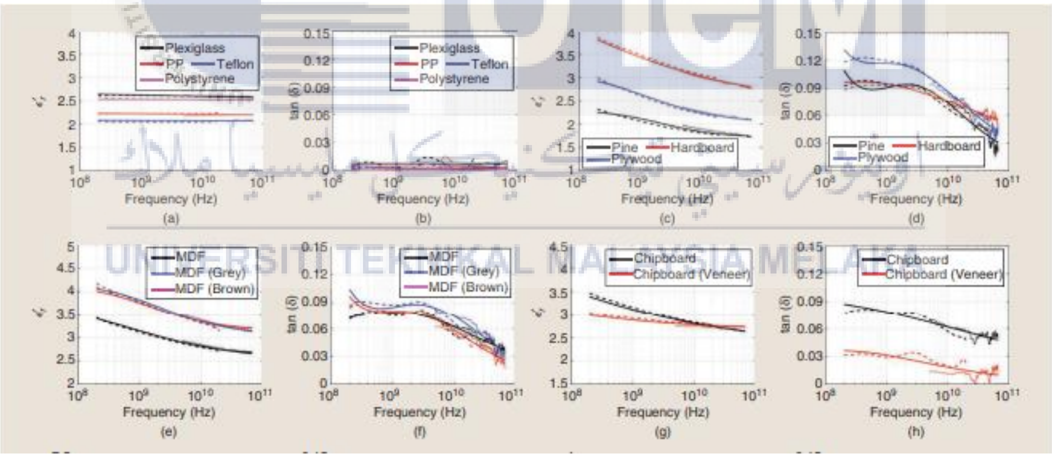


Figure 2.11 The measured and modelled real part of the complex relative permittivity

2.4.4 High-Efficiency and High-Uniformity Microwave Water Treatment System Based on Horn Antennas

In an article by Ren Xuan Tan, published in the year 2020, A device that generates and disperses microwave energy uniformly over water utilizes horn antennas and is known as a high-efficiency and high-uniformity microwave water treatment system. By heating the water, microwave energy assists in the removal of impurities or the inactivation of microorganisms. Energy efficiency, homogeneous treatment, quick processing, selective heating, and chemical-free treatment are some advantages of this method [17].

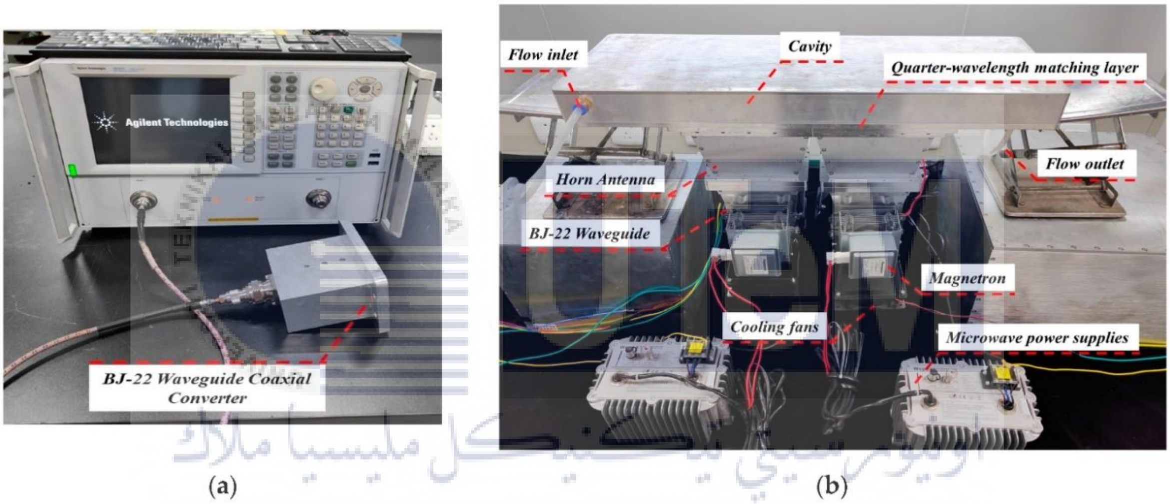


Figure 2.12 (a) Vector network analyzers (VNA); (b) photo of the experimental

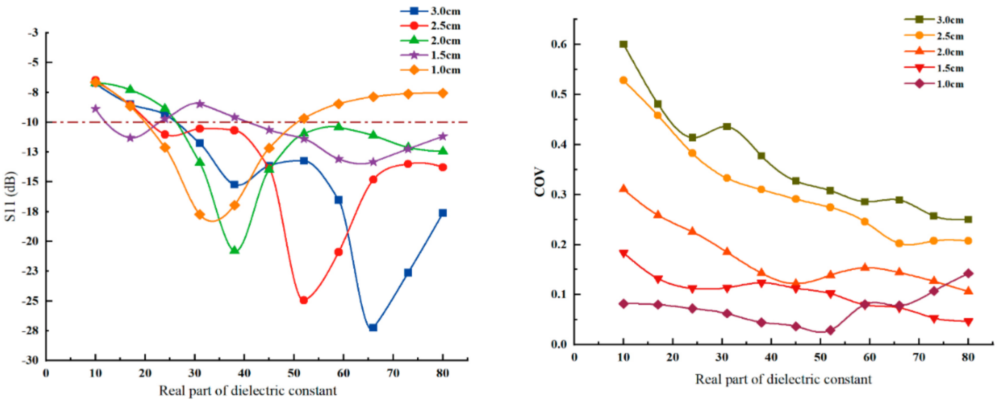


Figure 2.13 Effect of the real part of the dielectric constant Microwave open-ended coaxial dielectric probe

In an article by Meaney P, published in the year 2019, A microwave open-ended coaxial dielectric probe's sensing volume is the area in and around the probe's open end where the material's dielectric characteristics are determined. It represents an average value within that range and extends a few microns beyond the open end. The design of the probe and its operating frequency determine the size and shape of the sensing chamber. When interpreting the measurements, it is crucial to take into account the impact of the immediate environment and any potential interactions with nearby materials. Measurement accuracy can be increased by calibration processes and mathematical modelling [18].

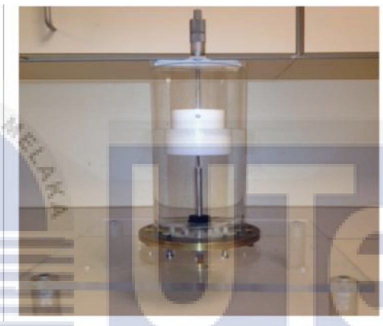


Figure 2.14 Photograph of the physical test configuration showing the cylindrical tank, dielectric probe, and coupling liquid, with the Teflon block and depth micrometer mounted to the top of the tank

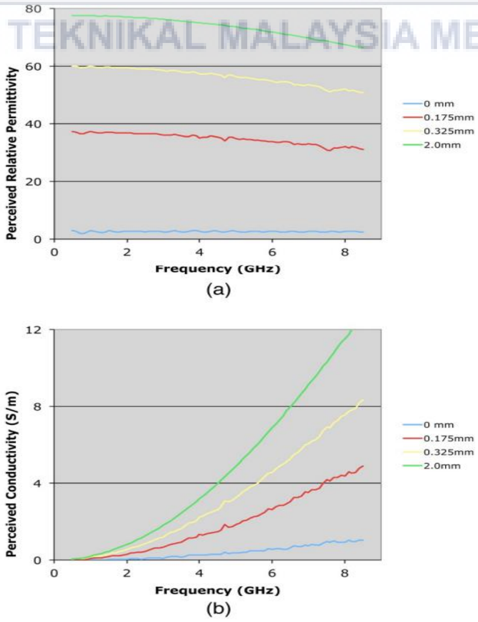


Figure 2.15 (a) Relative permittivity, and (b) conductivity

2.4.5 High-sensitivity dielectric resonator-based waveguide sensor for crack detection on metallic surfaces

In the year 2019 an article published by Wang Q, makes the following points. For crack detection on metallic surfaces, a high-sensitivity waveguide sensor with a dielectric resonator is used. It comprises a waveguide and a dielectric resonator. The resonator detects changes in the electromagnetic field and changes in the resonant frequency or quality factor as a result of electromagnetic waves interacting with surface fractures. The sensor can precisely identify and gauge the size and depth of cracks by observing these changes. It is frequently employed in non-destructive testing and evaluation to make sure that metal constructions are reliable and safe [19].

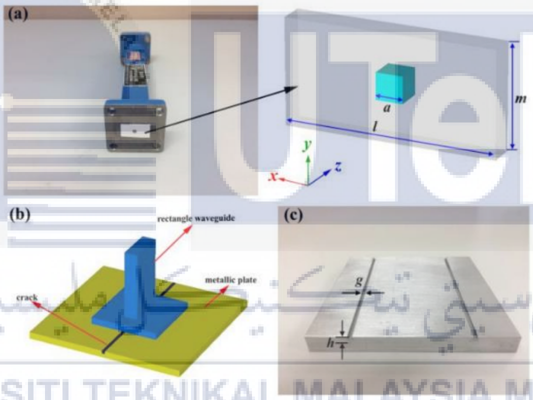


Figure 2.16 (a) Dielectric resonator-based waveguide sensor. (b) Diagram of the setup for long cracks detection on a metallic surface. (c) Metallic (Aluminum) plate sample

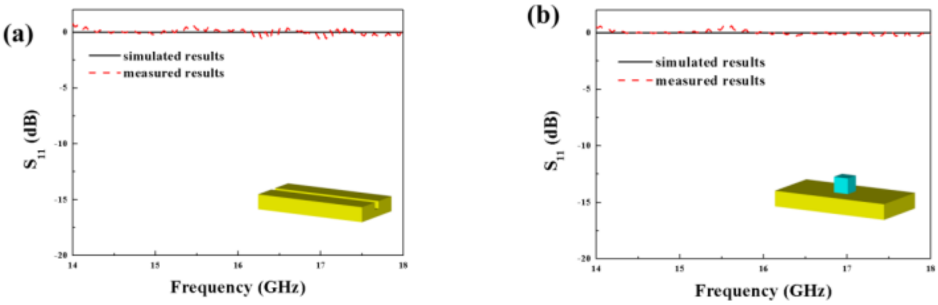


Figure 2.17 Simulated and measured reflection coefficient S11 (a) The waveguide probe without dielectric resonator (b) The dielectric resonator-based waveguide sensor on a defect-free metallic plate

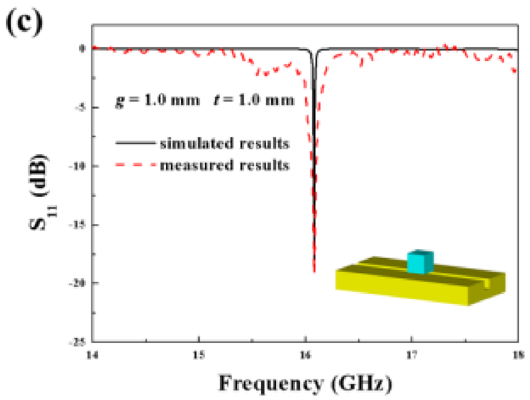


Figure 2.18 (c) The dielectric resonator based waveguide sensor on a metallic plate with a crack.

2.4.6 Simplified Approach to Detect Dielectric Constant Using a Low-Cost Microfluidic Quarter Mode Substrate Integrated Waveguide

In the year 2020 an article published by Ahmed Salim, Study presented a three-material calibration-based, portable, and reasonably priced RF sensor system to measure relative permittivity. For high QF and miniaturization, we designed and made a 4-port QMSIW resonator. Three of the four QMSIW ports make use of well-known liquids (such as air, ethanol (23% by volume), and DI water) to provide automatic calibration. To determine the dielectric constant for a test liquid, the proposed simplified method evaluates return loss and reflection coefficient magnitude. To experimentally demonstrate the suggested idea, we created a prototype system that included a 4-port QMSIW resonator, VCO, RF detector, and MCU. The prototype's relative permittivity’s for various concentrations of ethanol—100%, 70%, 50%, and 25%—as well as saline—0.5%, 1%, and 2%—were measured, and the results were contrasted with those from a Keysight N1501A commercial dielectric probe.

There was a 0.52-3.89% difference between the suggested sensor system and the commercial device, with a 1% difference for the test liquid dielectric constant of 20. This means that the suggested sensor system may measure liquid dielectric constants at a very low cost in a single small module without the need for a VNA. For liquids with low dielectric constants, the suggested simplified method performs well. By combining and realising all components on a single chip, the overall size might be further decreased for practical applications, considerably expanding the potential application breadth [20].

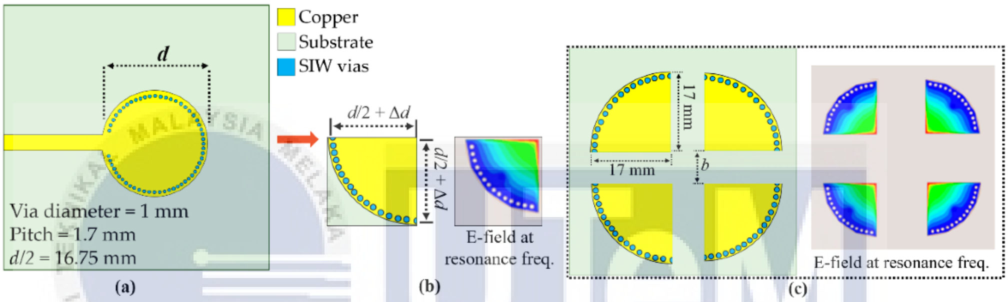


Figure 2.19 Simplified Approach to Detect Dielectric Constant Using a Low-Cost Microfluidic Quarter Mode Substrate-Integrated Waveguide

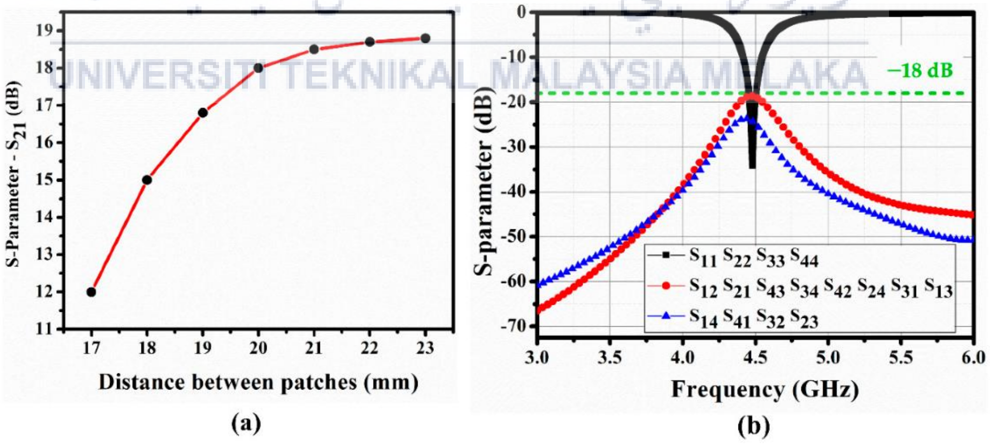


Figure 2.20 (a) Simulated isolation between ports 1 and 2(s21) for different distances, a, between quarter-mode substrate integrated waveguide (QWSIW) segments, (b) S-parameters for 4 port QWSIW at b=20mm

2.4.7 Evaluation of Dielectric Properties of Coloured Resin Plastic Button to Design a Small MIMO Antenna

In an article wrote in the year 2020 by, Kumar Biswas, A simple, low-profile, two-port MIMO antenna is shown for wearable applications. The button's dielectric properties are researched over a broad frequency range, from 1 to 15 GHz, prior to building the antenna. The proposed prototype is designed using only the researched dielectric homes for the target band. Two partially semi-circular elements with a frequency range of 7.96 GHz to 8.76 GHz are used in the antenna. To provide high port isolation, a straightforward copper ring is integrated around its four sewing holes. Over the whole software band, isolation is accomplished at a minimum level of around 21 db. The suggested antenna is capable of operating in all ITU (8 to 8.5 GHz) frequency bands. Along with extreme isolation, it also displays very acceptable values for the total active reflection coefficient (TARC), mean effective achieve (MEG), channel potential loss (CCL), range reap (DG), and envelope correlation coefficient (ECC) across the whole usable band. The button MIMO antenna is a suitable candidate for the desired function zones based on radiation characteristics [21].

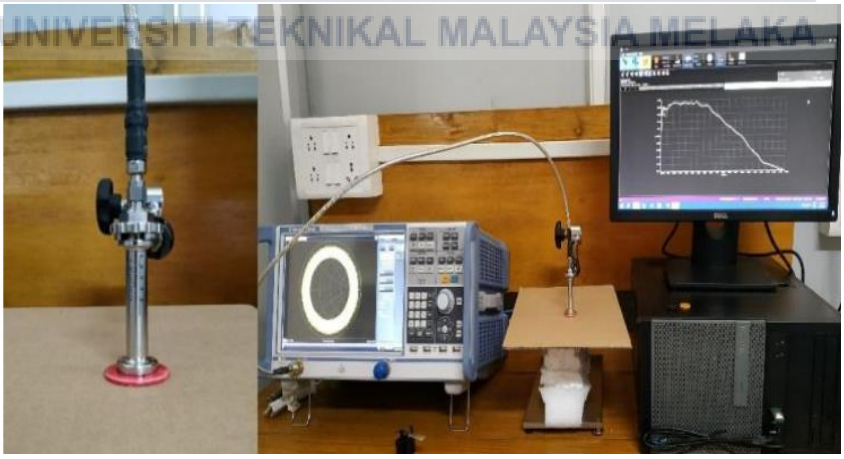


Figure 2.21 Representation of measurement set-up to measure the dielectric properties of the button

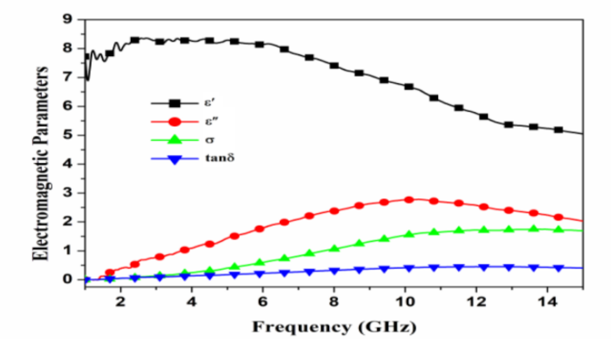


Figure 2.22 Measured dielectric properties of the button over 1-15 GHz frequency range

2.4.8 A Novel Contactless Dielectric Probe for On-Wafer Testing and Characterization in the V-Band

In a piece of writing from 2019 published by Mohamad A. Basha, A brand-new contactless dielectric probe is presented. In the V-band, two probes have been created, constructed, and tested. One probe's initial measurement had an insertion loss of more than 1 dB. An insertion loss of 2dB for the frequency range of 55 GHz to 75 GHz is predicted using a two-probe check configuration, with a substantial portion of the losses coming from angular misalignment. The wafer trying out and characterization of dielectric waveguides can be done using the dielectric probe [22].

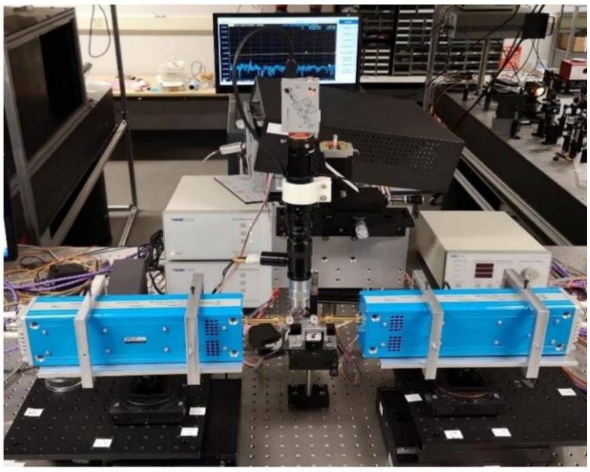


Figure 2.23 Two port test setup of the dielectric probe measurements

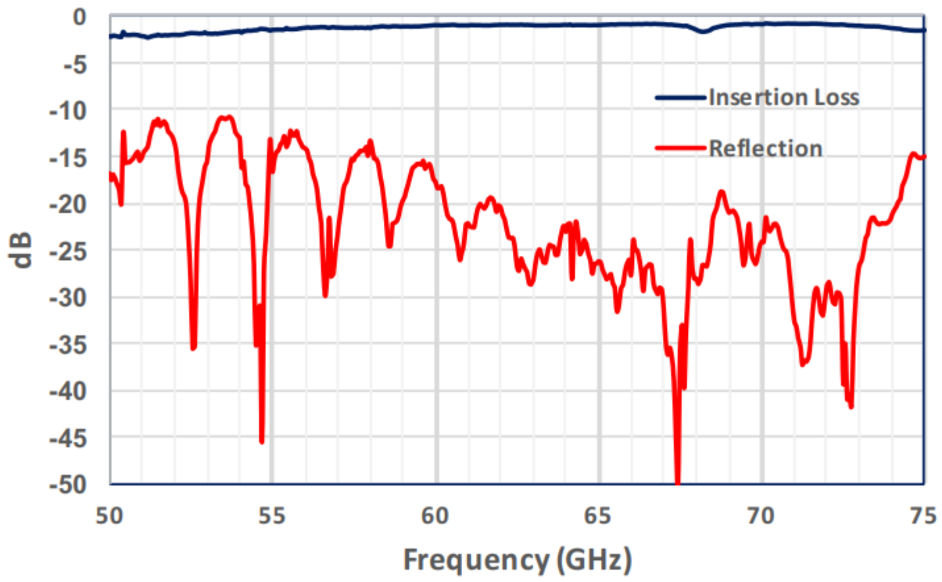
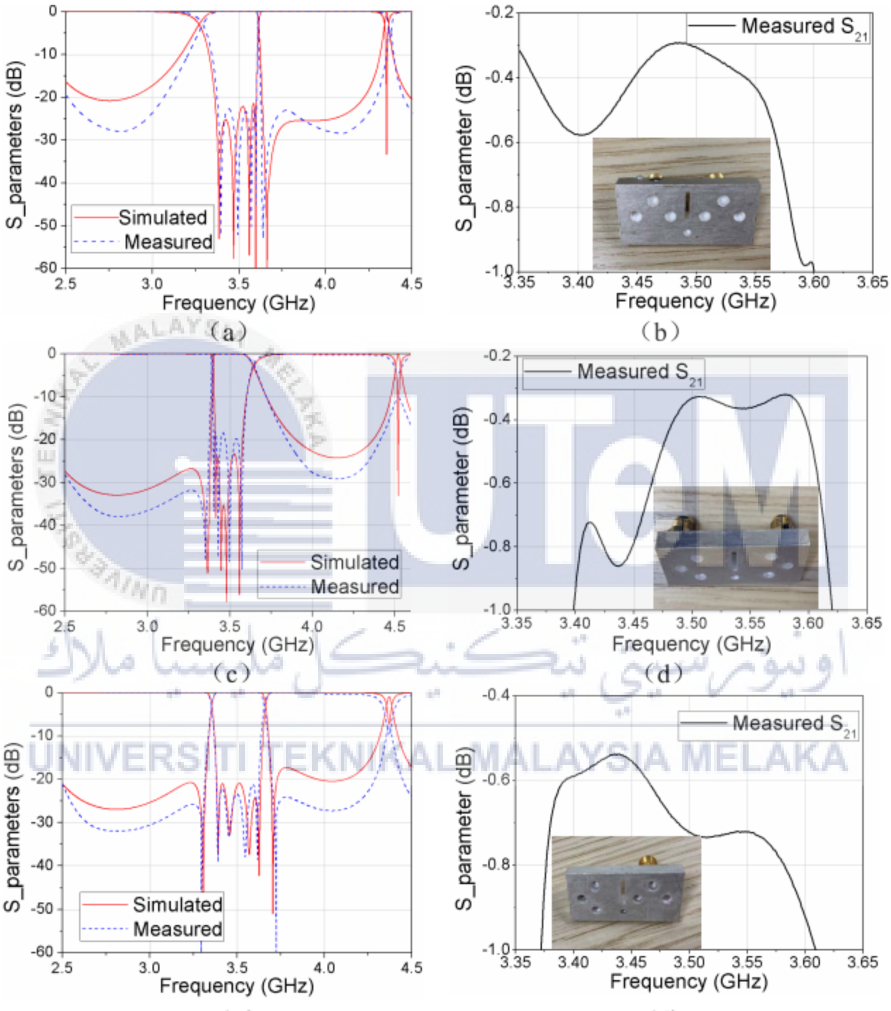


Figure 2.24 measured insertion and return loss of one dielectric probe

2.4.9 Dual-Mode Dielectric Waveguide Filters With Controllable Transmission Zeros

In an article by Huang Z, published in the year 2019, A form of filter design that makes use of dielectric waveguides to enable dual-mode operation and offers the ability to regulate the locations of gearbox zeros is a dual-mode dielectric waveguide filter with controllable gearbox zeros. The waveguide in such filters can accommodate two orthogonal modes that propagate simultaneously. The waveguide's geometry and dimensions can be carefully planned such that the filter can produce transmission zeros at particular frequencies within the passband or stopband. The frequency response of the filter is greatly shaped and enhanced by the use of these gearbox zeros.

Engineers can modify the filter response to match particular requirements thanks to programmable gearbox zeros. It is possible to change the positions of transmission zeros and affect the frequency response of the filter by varying the design parameters, such as the waveguide size or the placement of perturbations inside the waveguide. Various capabilities, such boosting out-of-band rejection, improving selectivity, or obtaining particular passband characteristics are made possible by the ability to adjust transmission zeros. These filters are used in a variety of industries, such as optical communications, radar systems, and wireless communications. To attain the desired performance parameters, complex electromagnetic modelling approaches, optimisation algorithms, and simulation tools are used in the design and optimisation of dual-mode dielectric waveguide filters with controlled transmission zeros [23].



(a) (b)

(c) (d)

(e) (f)

Figure 2.25 Measured and simulated results. (a) and (b) TZ set above. (c) and (d) TZ set below. (e) and (f) TZs set above and below

2.5 Advantages and Disadvantages of the previous projects

Table 2.1 Advantages and disadvantages of Related Previous Project

No	Title	Authors	Ref no	Year	Advantages	Disadvantages
1	Open-ended coaxial probes used to gather dielectric properties of biological tissues advantages and disadvantages in point form	G. Maenhout	[14]	2020	• Accurate measurements • Wide frequency range	• Limited spatial resolution • invasive
2	Transmission Phase-Shift Method for Complex Permittivity Determination of Biological Sample Performed Using X-Band Rectangular Waveguide	M.R. Effendi	[15]	2020	• Accurate measurements • Wide frequency range	• Equipment complexity • Time-consuming
3	Dielectric Properties of Common Building Materials for Ultrawideband Propagation Studies	Zhekov S, Franek	[16]	2020	• low-loss • Wide frequency range:	• Reflections and multipath effect • Dispersion
4	High-Efficiency and High-Uniformity Microwave Water Treatment System Based on Horn Antennas	Ren Xuan Tan	[17]	2020	• Rapid and efficient heating • Scalability	• Limited penetration depth • Potential safety hazards
5	Microwave open-ended coaxial dielectric probe	Meaney P	[18]	2019	• Non-destructive testing • Compact and portable	• Calibration challenges • Limited versatility for complex structures

6	High-sensitivity dielectric resonator-based waveguide sensor for crack detection on metallic surfaces	Wang Q	[19]	2019	• Fast and real-time detection • High-resolution imaging	• Limited application to specific crack type • Sensitivity to surface conditions
7	Simplified Approach to Detect Dielectric Constant Using a Low-Cost Microfluidic Quarter Mode Substrate-Integrated Waveguide	Salim A	[20]	2019	• Real-time measurements • Simplified design and operation	• Expertise and maintenance requirements • Limited sample volume
8	Evaluation of Dielectric Properties of Coloured Resin Plastic Button to Design a Small MIMO Antenna	Kumar Biswas	[21]	2020	• Material characterization • Cost-effective material choice	• Measurement challenges • Environmental effects
9	A Novel Contactless Dielectric Probe for On-Wafer Testing and Characterization in the V-Band	Mohamed A. Basha	[22]	2019	• Non-contact measurement • Compact and integrated design	• Limited versatility for other frequency ranges • Limited depth of penetration
10	Dual-Mode Dielectric Waveguide Filters With Controllable Transmission Zeros	Huang Z	[23]	2021	• Low insertion loss • High power handling capability	• Higher cost compared to some alternatives • Sensitivity to manufacturing tolerances

2.6 Summary

In conclusion, the dual-ended waveguide method has been broadly used to measure the dielectric properties of more than a few materials, which include liquids, biological tissues, and layered media. This method involves measuring the scattering parameters of the waveguide with and beside the sample and then the usage of a complicated reflection coefficient algorithm to calculate the complex permeability of the material. This science has many applications in microwave engineering, materials science, and biomedical engineering.

CHAPTER 3

METHODOLOGY

3.1 Introduction

The methodology section outlines the experimental procedures and techniques used to design and fabricate the dielectric probe. The overall objective of the methodology is to develop an efficient dielectric probe measuring tool that can be used to measure the dielectric substrate correctly. There are many steps which are stated in the below paragraph

The first and far most important thing that we will need is a flow chart for this project. Next, the second most important thing is to create a CST Microwave Studio simulation. In CST designing the waveguide is the most important equipment for this project. After that, the following step will be the fabrication. The third step involves fabricating the substrate materials, such as RT Duriod 5880 and FR-4.

The methodology section has been provided with a detailed description of each step, including the materials and equipment used, the experimental setup, and the data analysis techniques. This section also discussed potential limitations and challenges associated with each step and proposed strategies to overcome them. The methodology section aims to provide a comprehensive and reproducible experimental procedure for the Development Of a Dielectric Properties Measurement System Using a dual-ended waveguide using CST software.

3.2 Sustainable Development

Sustainable dielectric probe development offers a substantial measurement technological advance, providing special benefits and advancing us towards a future characterised by environmental stewardship. These probes have incredibly low power requirements while operating, which lowers the entire carbon footprint connected with measurement operations. Sustainable dielectric probes that put an emphasis on energy efficiency are in line with our pressing need to combat climate change and use as little energy as possible. Sustainable dielectric probes reduce waste by doing away with the need for consumable or disposable parts, in addition to being energy efficient. Sustainable probes are made of strong, long-lasting materials, as opposed to conventional probes that frequently need to be replaced or calibrated. This emphasis on toughness ensures prolonged use and considerably reduces waste formation, improving resource efficiency.

The capacity of sustainable dielectric probes to do non-destructive testing is one of its most important benefits. Traditional measuring methods frequently entail sample alterations or destruction, which results in extra sample preparation and resource waste. Sustainable dielectric probes, on the other hand, allow accurate measurements without harming the sample, negating the need for time-consuming sample preparation and sparing priceless resources. The choice of material is crucial for the long-term development of dielectric probes. The environmental impact of the probe is reduced over the course of its life by choosing environmentally friendly materials, such as biodegradable or recyclable materials. Further strengthening the sustainability of these probes is the use of non-toxic materials, which guarantee the safety of users and the ecosystem.

Another essential component of developing sustainable dielectric probes is designing for endurance. These probes limit the need for replacements and repairs by prioritising durability and robustness in their design, minimising waste production and protecting precious resources. Conscious engineering and the use of robust materials encourage sustainable behaviour and lessen the total environmental impact of measurement systems. Dielectric probes can be combined with renewable energy sources to increase their sustainability. Sustainable probes can use less on traditional power sources by including technology like solar panels or energy harvesting devices, which will lessen greenhouse gas emissions and hasten the transition to a low-carbon future. Dielectric probes' sustainability credentials are further strengthened by this incorporation of renewable energy, which also better aligns them with more general environmental objectives.

Achieving a circular economy and reducing negative environmental effects depend on the ethical disposal and recycling of dielectric probes. The recovery of priceless materials is ensured by the application of thorough lifecycle management systems, which also guard against potential environmental pollution. Sustainable dielectric probes contribute to a measurement ecology that is more resource-effective and sustainable by adopting ethical end-of-life procedures. Future technological developments in the creation of dielectric probes hold enormous promise for improving sustainability. Increased energy efficiency, lower material usage, and more streamlined measurement procedures may result from future research in miniaturisation, wireless connectivity, and enhanced measurement algorithms. With these developments, dielectric probe technology will innovate and achieve even higher sustainability improvements.

Collaboration between researchers, producers, and end users is necessary to realise the full potential of sustainable dielectric probes. To encourage adoption and promote the usage of these probes in diverse industries, it is essential to raise knowledge about the environmental advantages of sustainable measurement practises. By working together, we can create a community that values sustainability and recognises the revolutionary potential of dielectric probes in the development of measurement technologies. In summary, sustainable dielectric probes combine non-destructive testing, energy economy, waste reduction, and material sustainability to offer a distinctive and novel approach to measuring technology. We can advance measurement techniques across industries while promoting environmental stewardship by embracing these probes. A greener, more sustainable future depends on the creation and broad use of sustainable dielectric probes.

3.3 Methodology

This thesis has present the calibration, sample preparation, probe placement, measurement setup, measurement process, data analysis, and interpretation, validation in order to make up the methodology for employing a measuring system same as the dielectric probe. Depending on the probe type and the material being measured, the precise stages may change. For appropriate usage, it is crucial to adhere to the manufacturer's recommendations and reference pertinent literature.

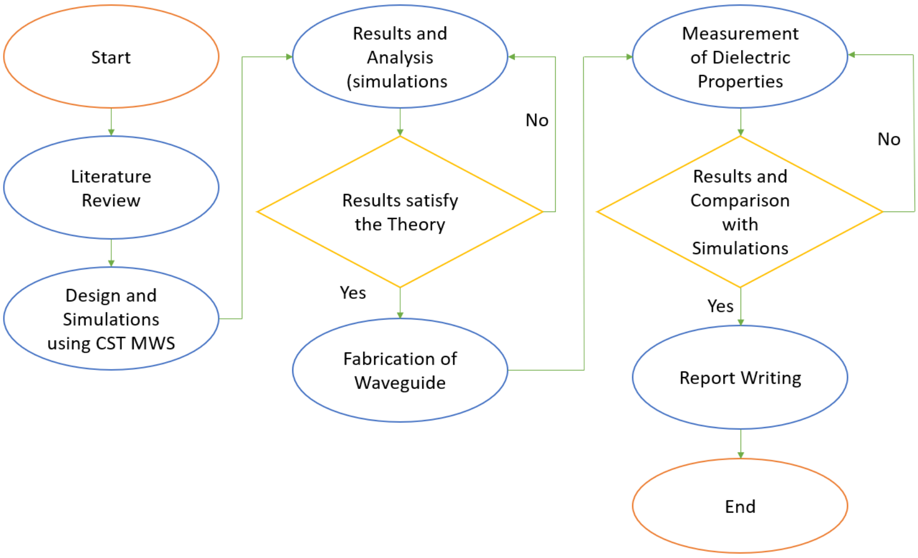


Figure 3.1 General Process of Flow Chart

3.3.1 Experimental setup

This thesis presents Development Of Dielectric Properties Measurement System Using Dual Ended Waveguide. The essence of the approach used in this project is centred on the concept waveguide. The method (design) is experimental, which utilizes empirical modelling and statistical approach. Subsequently, Figure 3.1 flow of this thesis. In this thesis the main highlights will be on software and hardware that are used.

3.3.2 CST Microwave Studio (CST MWS)

CST is a software which versatile 3D Simulation device for the fast and correct 3D EM simulation of high-frequency problems. Along with a broad utility range, it provides enormous product-to-market advantages, with the digital prototyping before physical trials; optimization as an alternative to experimentation. In this project, we will be constructing a rectangular waveguide. The design is almost similar to the Horn Type of antenna Equipment [24].

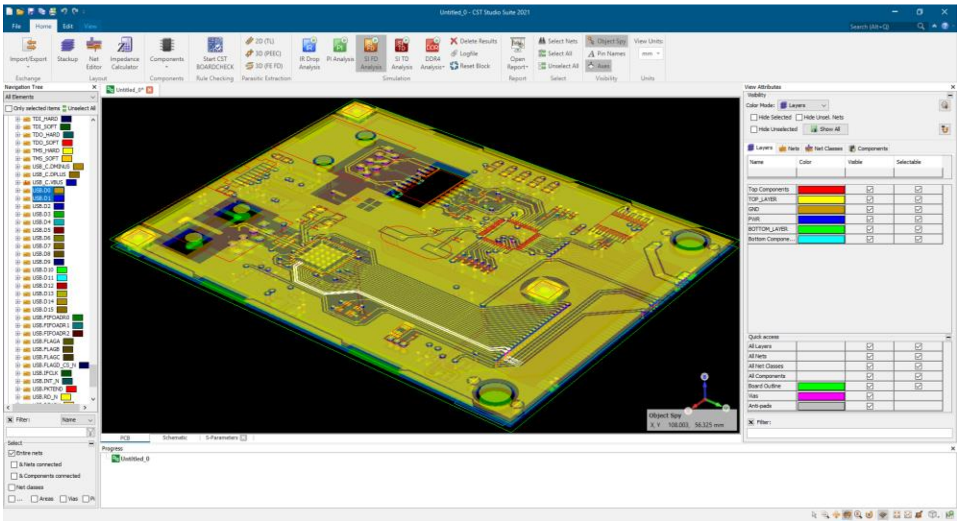


Figure 3.2 CST Microwave Studio

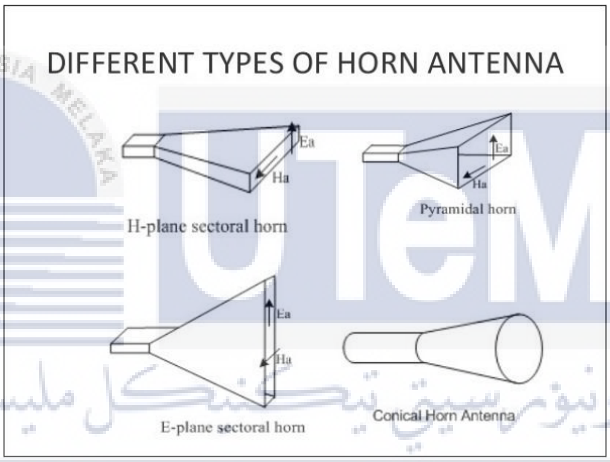


Figure 3.3 Different Type of Horn Antenna

3.3.3 2 Port Network Analyzer

The performance of a 2-port network, such as a circuit or device, is assessed using a 2-port network analyzer. It is frequently employed in radio frequency (RF) engineering, telecommunications, and electrical engineering. The equipment tested has two ports, and the network analyzer sends a signal to one of them and measures the response. This enables to ascertain the network's transfer function, impedance, and reflection coefficient, among other metrics. The vector network analyzer (VNA) and scalar network analyzer (SNA) are two popular varieties of 2-port network analyzer. While SNA simply measures the magnitude of the signal, VNA is more sophisticated and can measure both the magnitude and the phase of the signal. Applications for network analyzer include filter and amplifier design, as well as antenna testing. Anyone dealing with RF circuits and systems must have it [25].

Figure 3.4 2 Port Network Analyzer

3.3.4 Dual Ended Waveguide

In microwave engineering, a dual-ended waveguide is a particular kind of waveguide used for both transmitting and receiving electromagnetic signals. It is made up of a hollow conductor or a rectangular or cylindrical metal tube that is used to direct electromagnetic waves along its length. However, a rectangular waveguide is employed in this project. Dual-ended waveguides are a crucial part of microwave engineering and are employed in a number of applications where effective electromagnetic signal transmission and reception are essential. The size and geometries of dual-ended waveguides can be tailored to function at particular frequencies, resulting in effective and minimal loss electromagnetic wave propagation. Additionally, they are frequently covered in material that acts as a dielectric to lessen electromagnetic interference and improve signal transmission [26].

Figure 3.5 Diagram of rectangular waveguide

3.3.5 Aluminium Brick

An aluminium brick waveguide antenna is a type of antenna that uses a rectangular or square waveguide made of aluminium to transmit and receive electromagnetic waves, usually in the microwave frequency range. It provides good conductivity and mechanical strength. These antennas are commonly used in telecommunication, radar systems, satellite communications, and wireless networks. They have high power handling capability, low transmission loss, and are resistant to environmental factors. Integration with feeding mechanisms such as horn antennas enables efficient coupling of electromagnetic energy [27]

Figure 3.6 Real Diagram of Rectangular Waveguide

3.3.6 Coaxial Adapter

A coaxial adapter is designed to connect two coaxial cables or devices with distinctive coaxial connectors. These adapters come in a variety of types, such as F-type, BNC, or RCA, and have unique genders (male or female) and directionalities. They play a necessary function in scenarios where there is a want to bridge connections between gadgets with disparate coaxial connectors, such as in-home amusement systems, networking setups, or telecommunications infrastructure. It's necessary to pick the right adapter to in shape the connectors on the cables or gadgets being connected, considering factors like signal quality, weatherproofing for outside installations, and the particular application requirements. Coaxial adapters furnish flexibility and convenience in establishing connections while minimizing sign degradation[28].

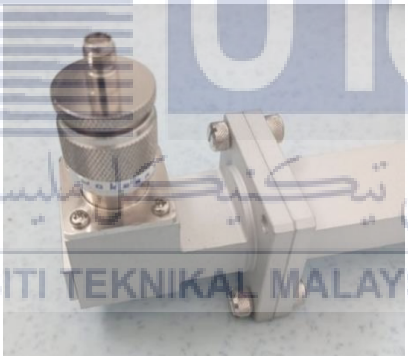


Figure 3.7 Coaxial Adapter

3.3.7 Screw

The foremost feature of a screw is to fasten objects together securely. With its helical thread, a screw engages with a complementary thread in some other object, developing a sturdy connection. Screws distribute pressure over a larger area, presenting steadiness and lowering the probability of joints loosening. They allow for each assembly and disassembly, supplying versatility and adjustability at some stage in installation. The mechanical advantage of the helical diagram skill that a small rotational force can generate a considerable axial force. Screws locate wide-ranging functions in construction, woodworking, electronics, and machinery, playing a vital role in a range of industries due to their reliability and adaptability.

Figure 3.8 Screw to combine the waveguide

3.3.8 The material used FR-4 and Rogers

FR-4 and Rogers are substances used in the manufacturing of printed circuit boards (PCBs). FR-4, or Flame Retardant 4, is a general glass-reinforced epoxy laminate recognised for its flame-retardant residences and mechanical strength, making it a common and most economical preference for general-purpose PCBs. On the different hand, Rogers refers to a household of high-performance PCB substrate materials designed for purposes requiring high-frequency performance, such as in microwave and RF circuits. Rogers substances provide particular dielectric constants, low-loss tangents, and managed impedance characteristics, making them appropriate for specialized and high-frequency applications. Designers select between FR-4 and Rogers based on the meant use and performance necessities of the PCB[29].

Figure 3.9 Rogers Board before and after removing the copper

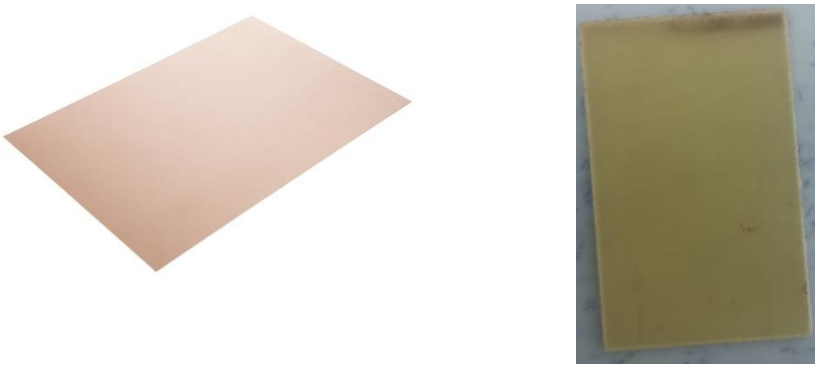


Figure 3.10 FR-4 Before and after Removing the Copper

3.4 Limitation of proposed methodology

The development of a dielectric properties measurement system using a dual-ended waveguide methodology has certain limitations that should be taken into account. These include the need for careful calibration to ensure accurate measurements, limitations in the frequency range that the system can effectively cover, considerations regarding the size and geometry of the samples being measured, susceptibility to environmental conditions such as temperature and humidity, challenges in characterizing complex or anisotropic materials, the complexity of data analysis and interpretation, and potential cost and accessibility issues associated with specialized equipment and expertise required. It is important to address these limitations to ensure the reliability and validity of the measurements obtained using this methodology [30].

3.5 Flow Chart of the Complete system and Project

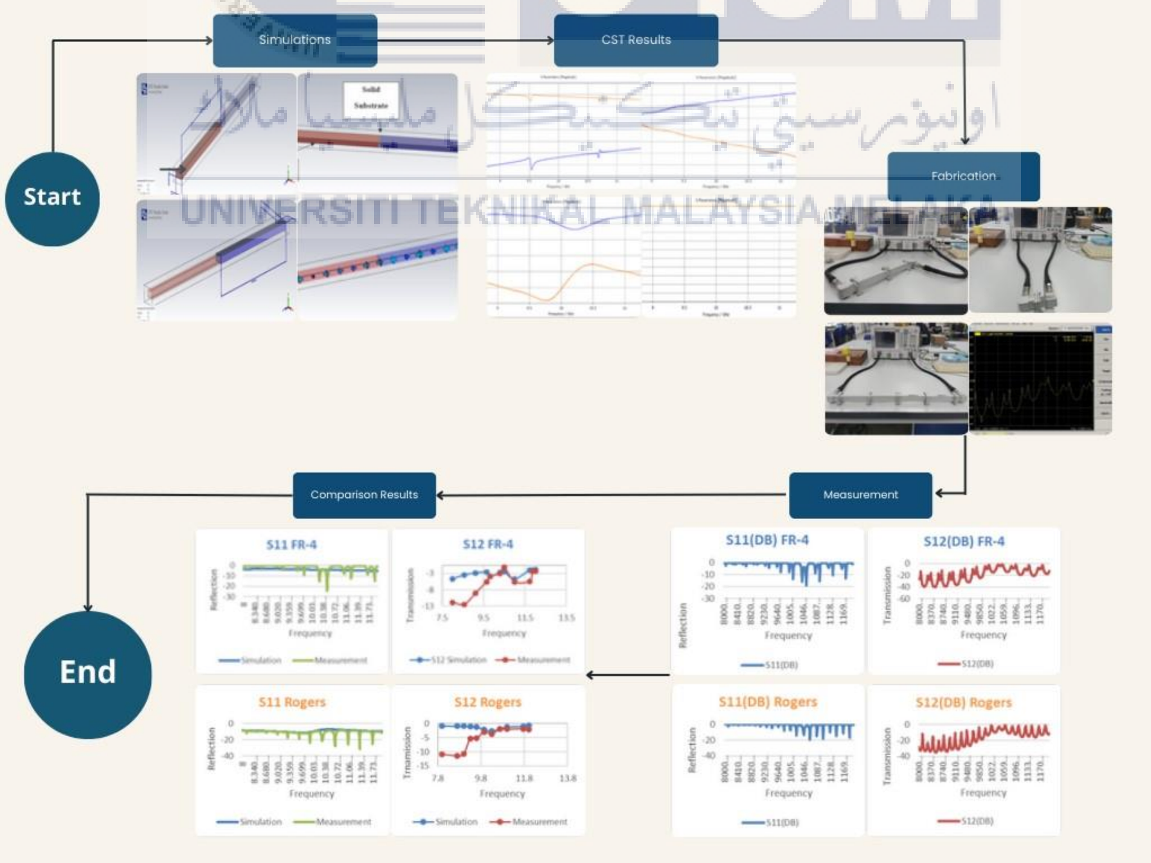


Figure 3.11 Flow of Project

3.6 Summary

The use of a dual-ended waveguide for measuring dielectric properties has limitations that need to be addressed. These limitations include the need for accurate calibration, restricted frequency range, considerations for sample size and shape, sensitivity to environmental conditions, challenges with complex materials, complex data analysis, and potential cost and accessibility issues. Despite these limitations, efforts to overcome them it can provide valuable information for the development of dielectric properties measurement systems using dual-ended waveguides.

CHAPTER 4

SIMULATION RESULTS AND ANALYSIS

4.1 Introduction

The study's results using a dual-ended waveguide methodology for measuring dielectric properties include obtaining accurate values for the dielectric constant and loss tangent of the tested materials. Additionally, an observation of frequency dependence in these properties and a comparison of the dielectric behaviour among different samples or materials is made. The study also involves validating the methodology against reference materials and conducting error analysis to assess measurement precision and uncertainty. The specific results are the same as the research objectives and materials being studied.

4.2 Results and Analysis

4.2.1 Design using CST microwave studio

In this CST design, An X-band frequency from 8 GHz to 12 GHz is used to design the waveguides. By using X-band frequency the values for the x and y axis are as follows for the width x is 22.86 and y will be -22.86. Moving on to the height, the x-axis is 10.16, and the y-axis is -10.16. Then to obtain the length of a waveguide an equation has been made. By using frequency 10GHz and the speed of light to get the lambda, the formula and calculation are given below.

$$\boxed{\begin{aligned}\lambda &= \frac{C}{f}\\ &= \frac{3\times 10^{8}}{10\times 10^{9}}\\ &= 30mm\end{aligned}}$$

By using the lambda value, we were able to get the length of the waveguide. The value of length is determined by 30mm multiple by 10λ, and the length for the waveguides is 300mm. There are 3 square blocks in the design containing waveguide 1, waveguide 2, and solid substrates.

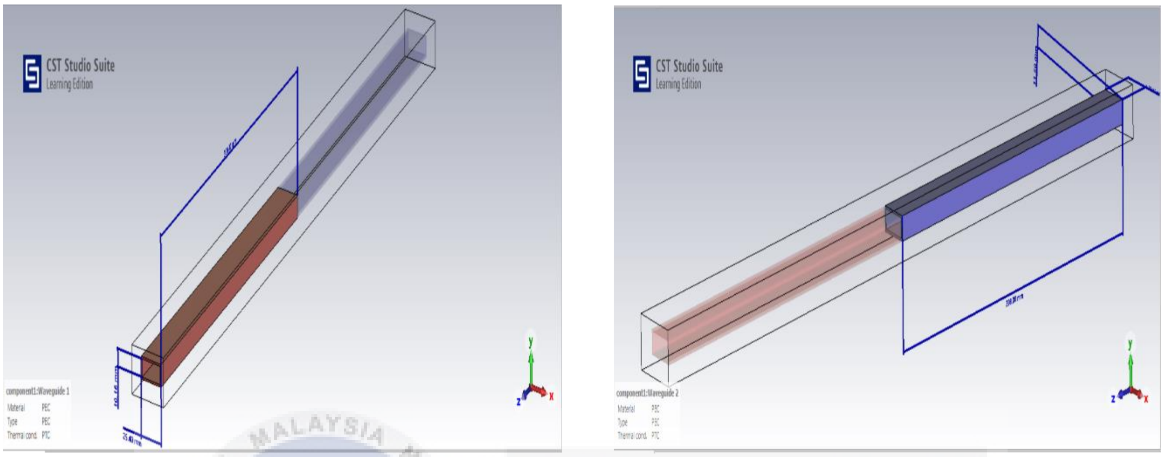


Figure 4.1 Rectangular Waveguide 1 and 2

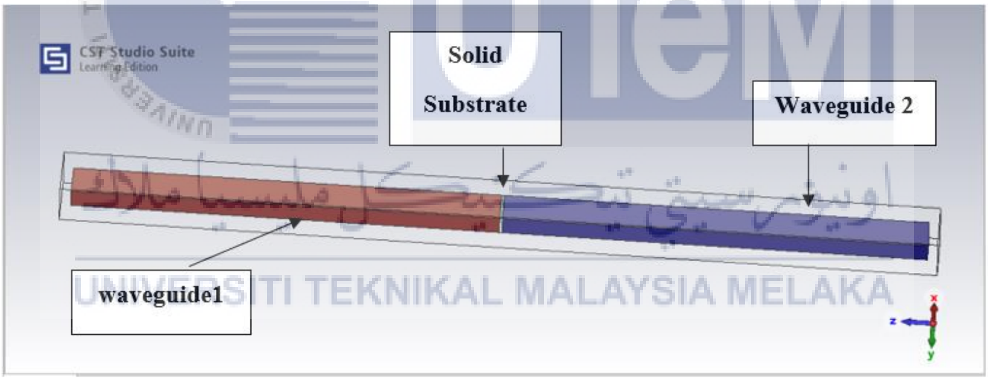


Figure 4.2 Complete Diagram

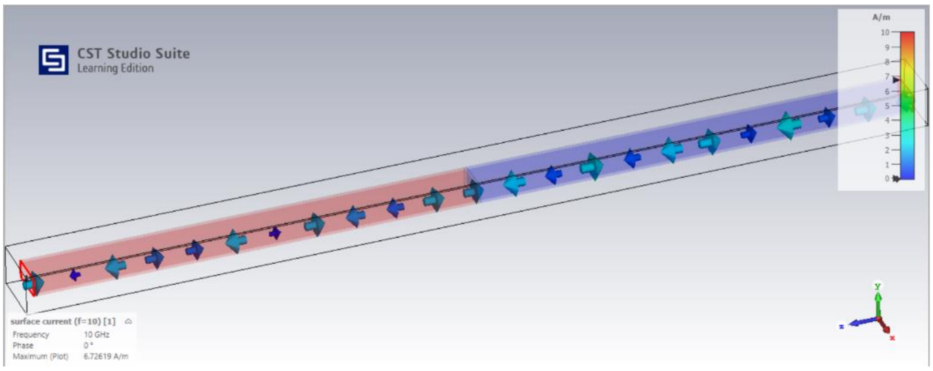
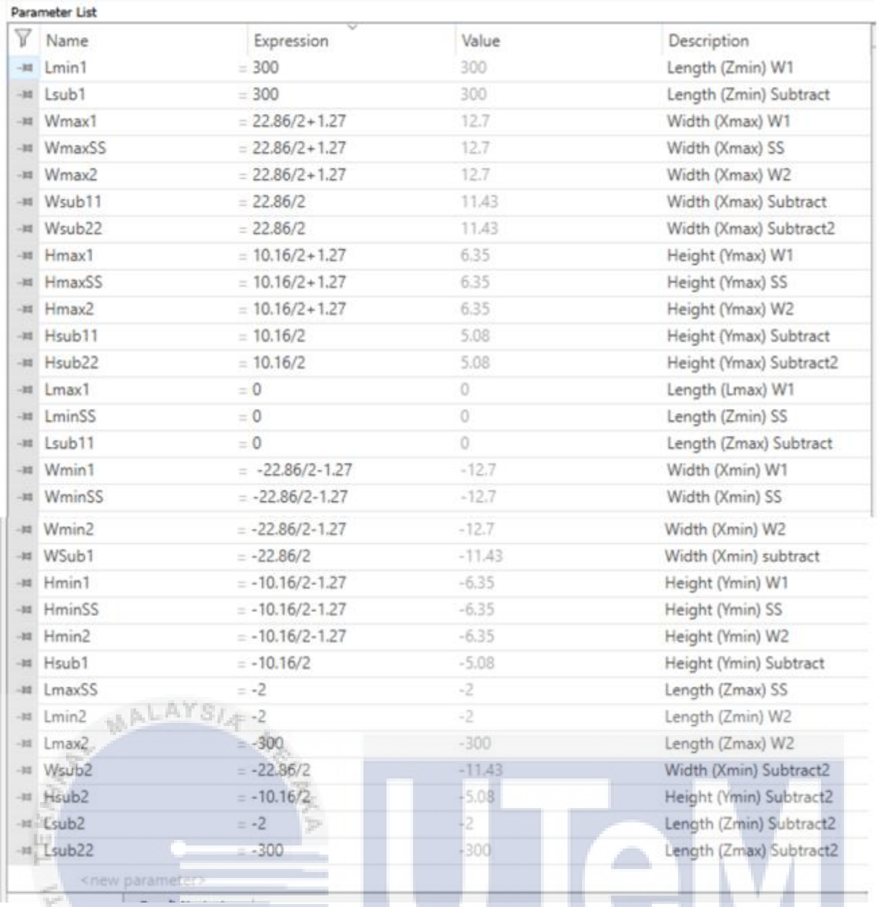


Figure 4.3 The E-field of the waveguide



Parameter List

Name	Expression	Value	Description
Lmin1	= 300	300	Length (Zmin) W1
Lsub1	= 300	300	Length (Zmin) Subtract
Wmax1	= 22.86/2+1.27	12.7	Width (Xmax) W1
WmaxSS	= 22.86/2+1.27	12.7	Width (Xmax) SS
Wmax2	= 22.86/2+1.27	12.7	Width (Xmax) W2
Wsub11	= 22.86/2	11.43	Width (Xmax) Subtract
Wsub22	= 22.86/2	11.43	Width (Xmax) Subtract2
Hmax1	= 10.16/2+1.27	6.35	Height (Ymax) W1
HmaxSS	= 10.16/2+1.27	6.35	Height (Ymax) SS
Hmax2	= 10.16/2+1.27	6.35	Height (Ymax) W2
Hsub11	= 10.16/2	5.08	Height (Ymax) Subtract
Hsub22	= 10.16/2	5.08	Height (Ymax) Subtract2
Lmax1	= 0	0	Length (Lmax) W1
LminSS	= 0	0	Length (Zmin) SS
Lsub11	= 0	0	Length (Zmax) Subtract
Wmin1	= -22.86/2-1.27	-12.7	Width (Xmin) W1
WminSS	= -22.86/2-1.27	-12.7	Width (Xmin) SS
Wmin2	= -22.86/2-1.27	-12.7	Width (Xmin) W2
WSub1	= -22.86/2	-11.43	Width (Xmin) subtract
Hmin1	= -10.16/2-1.27	-6.35	Height (Ymin) W1
HminSS	= -10.16/2-1.27	-6.35	Height (Ymin) SS
Hmin2	= -10.16/2-1.27	-6.35	Height (Ymin) W2
Hsub1	= -10.16/2	-5.08	Height (Ymin) Subtract
LmaxSS	= -2	-2	Length (Zmax) SS
Lmin2	= -2	-2	Length (Zmin) W2
Lmax2	= -300	-300	Length (Zmax) W2
Wsub2	= -22.86/2	-11.43	Width (Xmin) Subtract2
Hsub2	= -10.16/2	-5.08	Height (Ymin) Subtract2
Lsub2	= -2	-2	Length (Zmin) Subtract2
Lsub22	= -300	-300	Length (Zmax) Subtract2
<new parameter>			

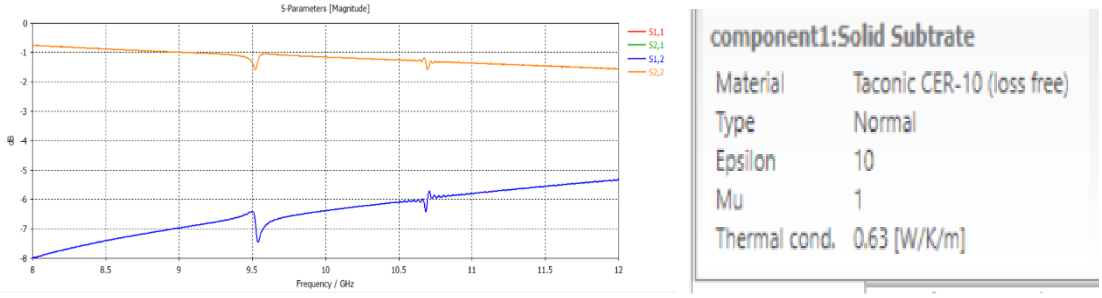
Figure 4.4 The Parameter list of the waveguides in Simulation

4.2.2 Simulation Results using different material

4.2.2.1 Dielectric Substrates

In the simulation results, 5 different types of solid substrates are used. The output frequency and the S-parameters are observed from this simulations. These parameters will help to characterize the dielectric properties of an materials.

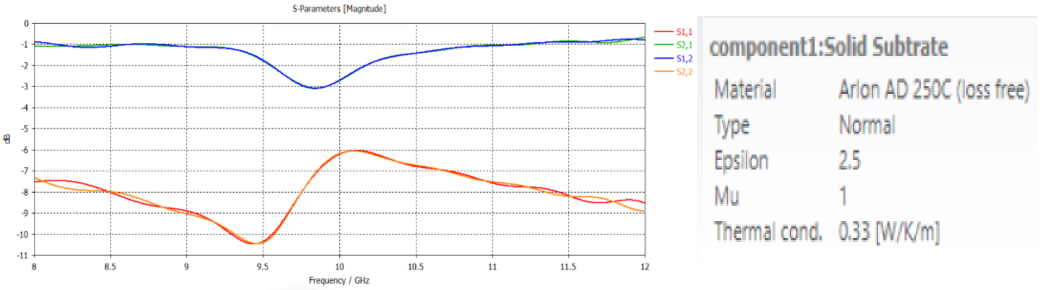
a) Taconic CER-10



component1:Solid Subtrate

Material	Taconic CER-10 (loss free)
Type	Normal
Epsilon	10
Mu	1
Thermal cond.	0.63 [W/K/m]

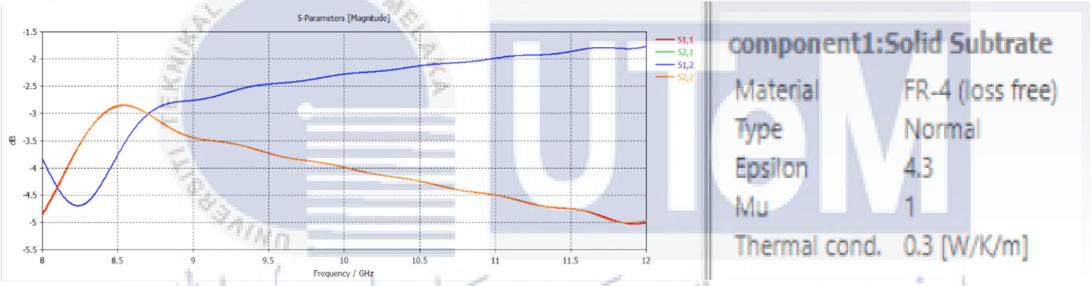
b) Arlon CLTE 11



component1:Solid Subtrate

Material	Arlon AD 250C (loss free)
Type	Normal
Epsilon	2.5
Mu	1
Thermal cond.	0.33 [W/K/m]

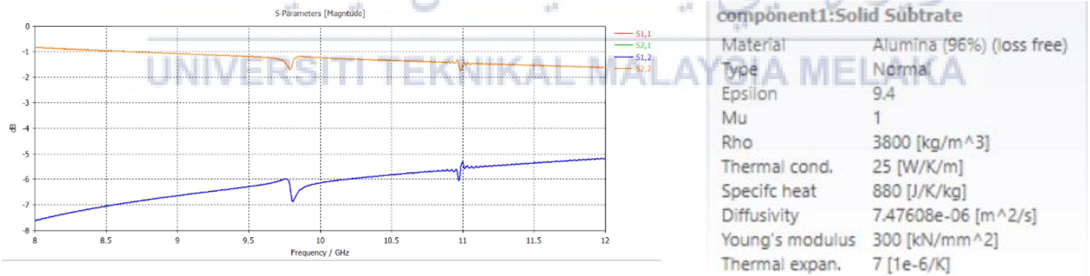
c) FR-4



component1:Solid Subtrate

Material	FR-4 (loss free)
Type	Normal
Epsilon	4.3
Mu	1
Thermal cond.	0.3 [W/K/m]

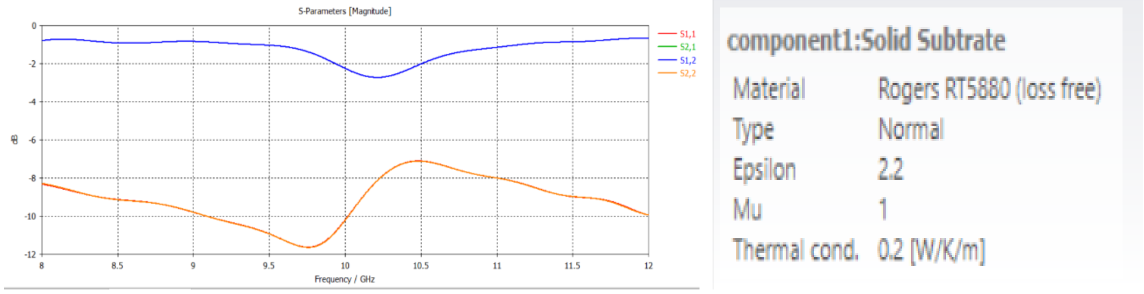
d) Alumina



component1:Solid Subtrate

Material	Alumina (96%) (loss free)
Type	Normal
Epsilon	9.4
Mu	1
Rho	3800 [kg/m^3]
Thermal cond.	25 [W/K/m]
Specifc heat	880 [J/K/kg]
Diffusivity	7.47608e-06 [m^2/s]
Young's modulus	300 [kN/mm^2]
Thermal expan.	7 [1e-6/K]

e) Rogers RT 5800



component1:Solid Subtrate

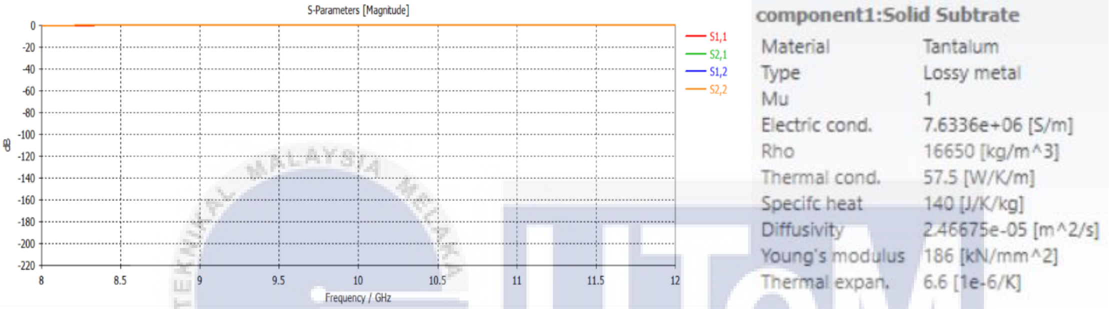
Material	Rogers RT5880 (loss free)
Type	Normal
Epsilon	2.2
Mu	1
Thermal cond.	0.2 [W/K/m]

Figure 4.5 The above images are the types of solid subtracted that have been used to measure the permittivity

4.2.2.2 Metal Substrate

Below are the materials which are metal. This simulation is done to show the difference between solid substrate and metal substrate. When metal type of solid substrates is used, the current or the electromagnetic wave will not pass through the substrate. Therefore, the S-parameter cannot be measured. This simulation is done by using 2 substrates.

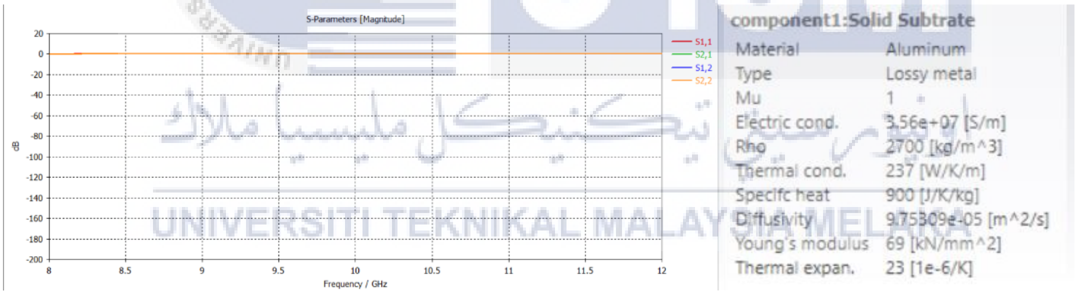
f) Tantalum



component1:Solid Subtrate

Material	Tantalum
Type	Lossy metal
Mu	1
Electric cond.	7.6336e+06 [S/m]
Rho	16650 [kg/m^3]
Thermal cond.	57.5 [W/K/m]
Specifc heat	140 [J/K/kg]
Diffusivity	2.46675e-05 [m^2/s]
Young's modulus	186 [kN/mm^2]
Thermal expan.	6.6 [1e-6/K]

g) Aluminum



component1:Solid Subtrate

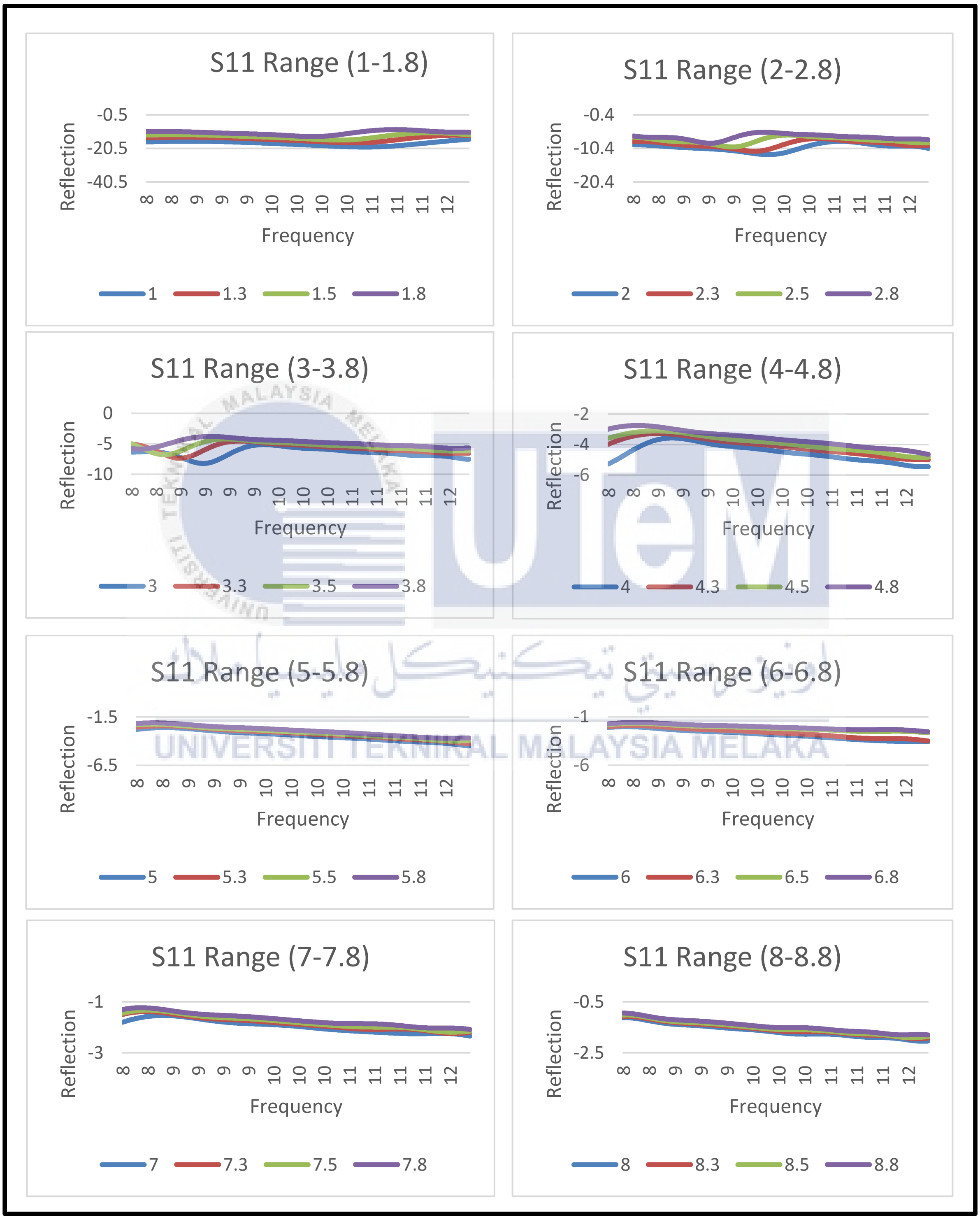
Material	Aluminum
Type	Lossy metal
Mu	1
Electric cond.	3.56e+07 [S/m]
Rho	2700 [kg/m^3]
Thermal cond.	237 [W/K/m]
Specifc heat	900 [J/K/kg]
Diffusivity	9.75309e-05 [m^2/s]
Young's modulus	69 [kN/mm^2]
Thermal expan.	23 [1e-6/K]

Figure 4.6 The above images are the types of solid subtracted that cannot be used to measure the permittivity

4.2.3 Simulation Results using different Permittivity, ε_r of the material.

In this simulation multiple numbers of permittivity are observe in the CST software. The numbers are from 1-12.8. The reason behind this simulation is in order to differentiate between the fabricated and simulated design with the material that are being used. Then, Multiple range has been done in order to make the process of fabrication easy as we need and not to worry about the range of permittivity of the board that has been purchased because we have all the results that we need.

a) Variable Permittivity Range between (1-12.8) for S11



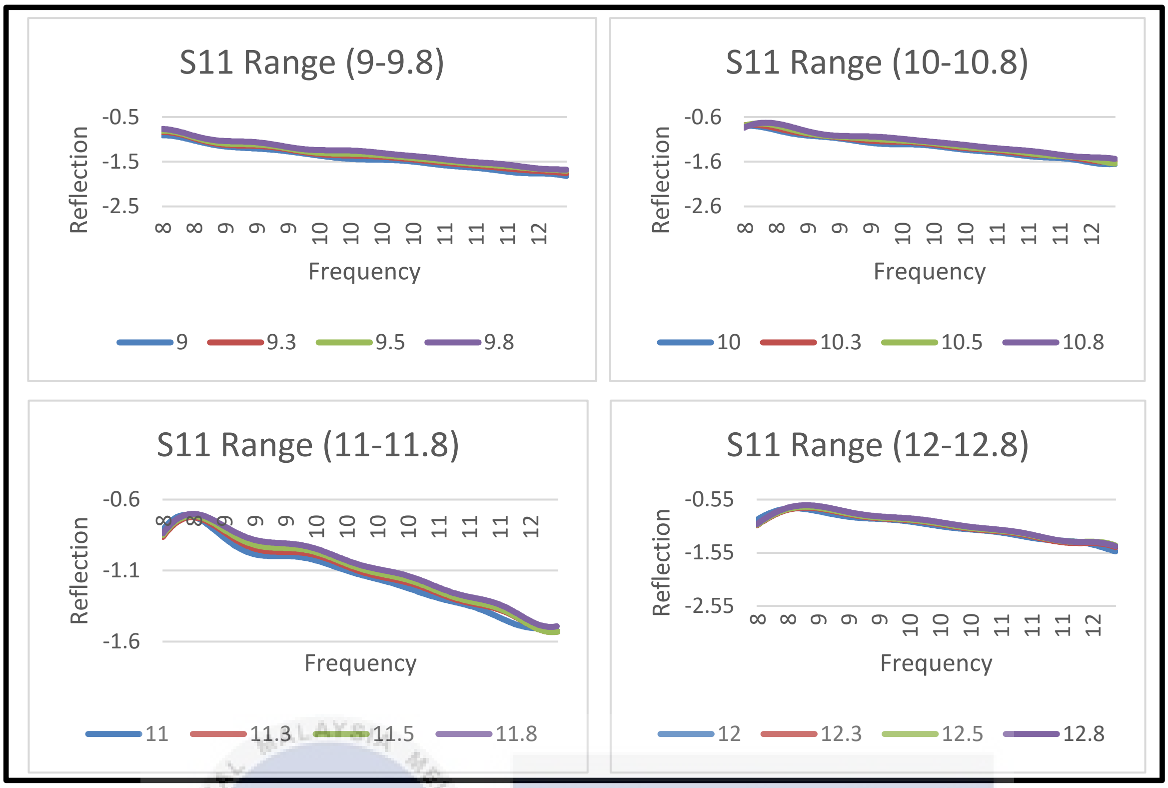
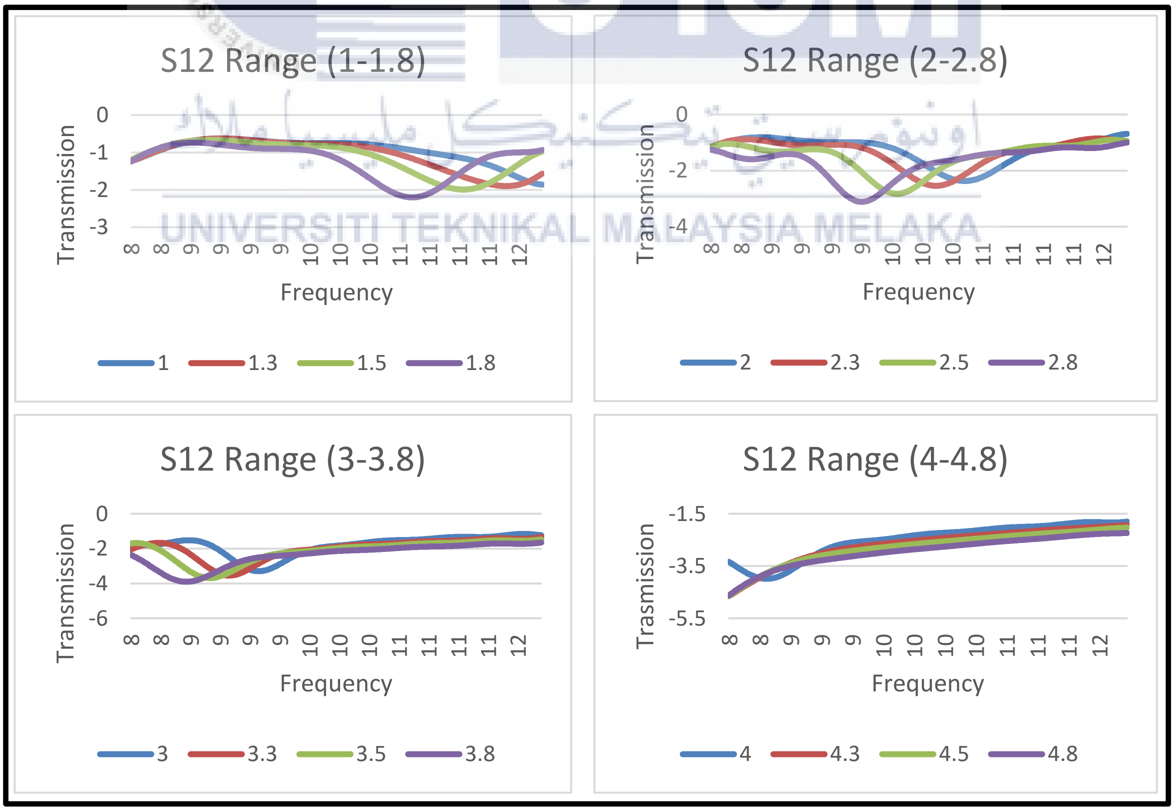


Figure 4.7 The above images shows the S- parameter of S11 range between 1 to 12.8

b) Variable Permittivity Range between (1-12.8) for S12



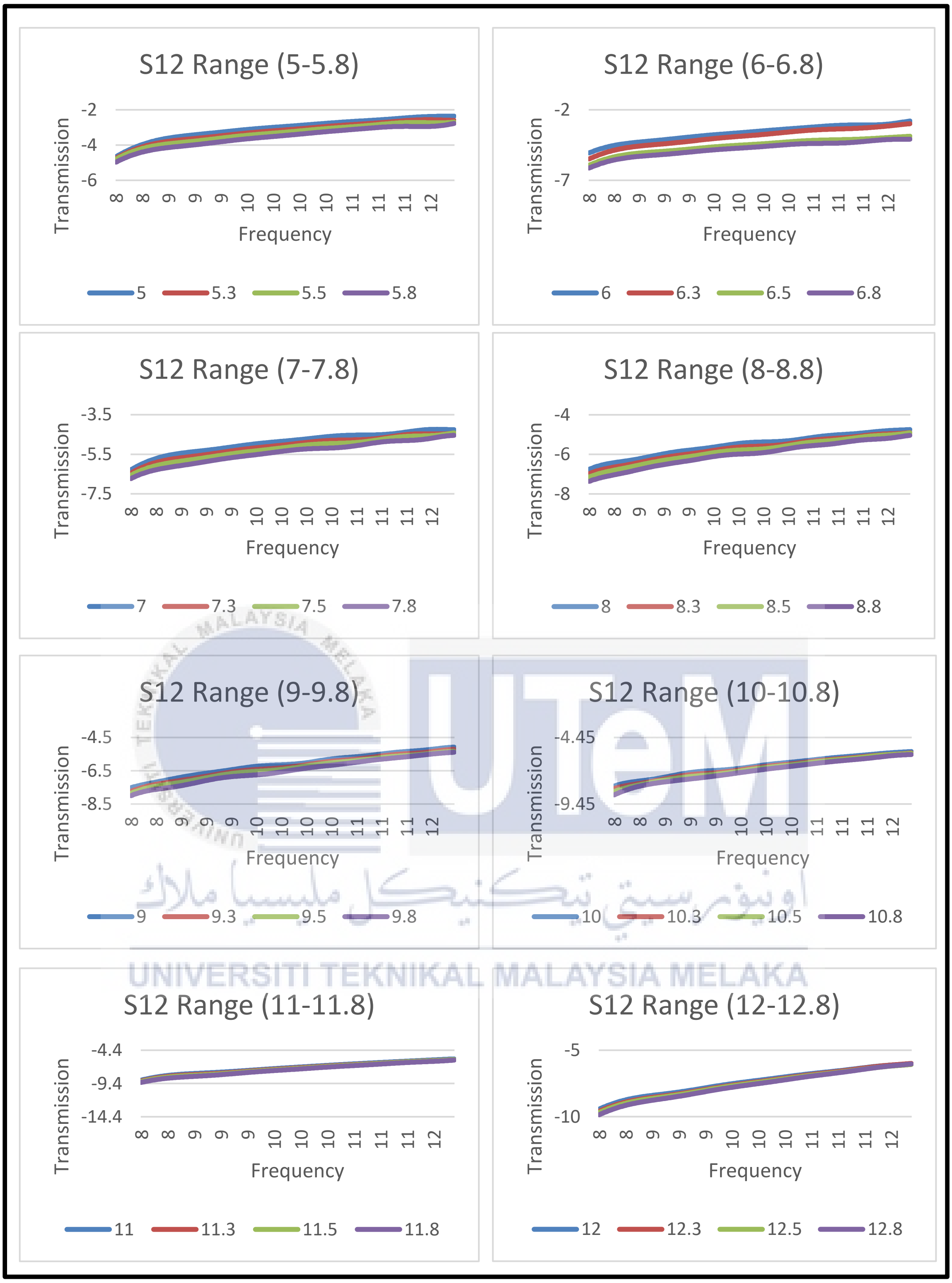


Figure 4.8 The above images shows the S-parameter of S12 range between 1 to 12.8

4.3 Summary

The study employs a dual-ended waveguide methodology to measure dielectric properties, focusing on obtaining accurate values for the dielectric constant and loss tangent of examined materials. The lookup involves observing frequency dependence and evaluating dielectric behaviour throughout special samples. The methodology is validated against reference materials, and error analysis is performed for measurement precision and uncertainty. The layout of the waveguides the use of CST Microwave Studio employs an X-band frequency (8 GHz to 12 GHz). The dimensions of the waveguides are decided based on calculations the usage of the speed of light and frequency. The simulation entails three components: waveguide 1, waveguide 2, and strong substrates.

The simulation outcomes encompass the use of one-of-a-kind dielectric substrates and metallic substrates. Five stable substrates (Taconic CER-10, Arlon CLTE 11, FR-4, Alumina, Rogers RT 5800) are analysed for their dielectric properties. Metal substrates like Tantalum and Aluminum are additionally simulated, highlighting their lack of ability to transmit electromagnetic waves. The learn about further explores the influence of varying permittivity (1-12.8) on S-parameters (S11 and S12) to differentiate between fabricated and simulated designs. The range of permittivity offers flexibility in fabric choice for fabrication. The figures illustrate the S-parameter versions throughout the permittivity range.

In summary, the lookup employs a dual-ended waveguide methodology with CST Microwave Studio to analyse dielectric properties, validate the methodology, and explore the effect of exceptional substrates and permittivity values on simulation results.

CHAPTER 5

MEASUREMENT RESULTS AND DISCUSSION

5.1 Measurement Methods and Results

There are 3 different ways that the experiment was conducted. The lab session was done using Dual-Ended waveguide design but the only change between the 3 of them was the length of the waveguide. The first result was using 2 waveguides, Next, was conducted by using 4 waveguides and the last one was only using the coaxial waveguide. Below are the images how the experiment was done and all the equipment has been labeled.

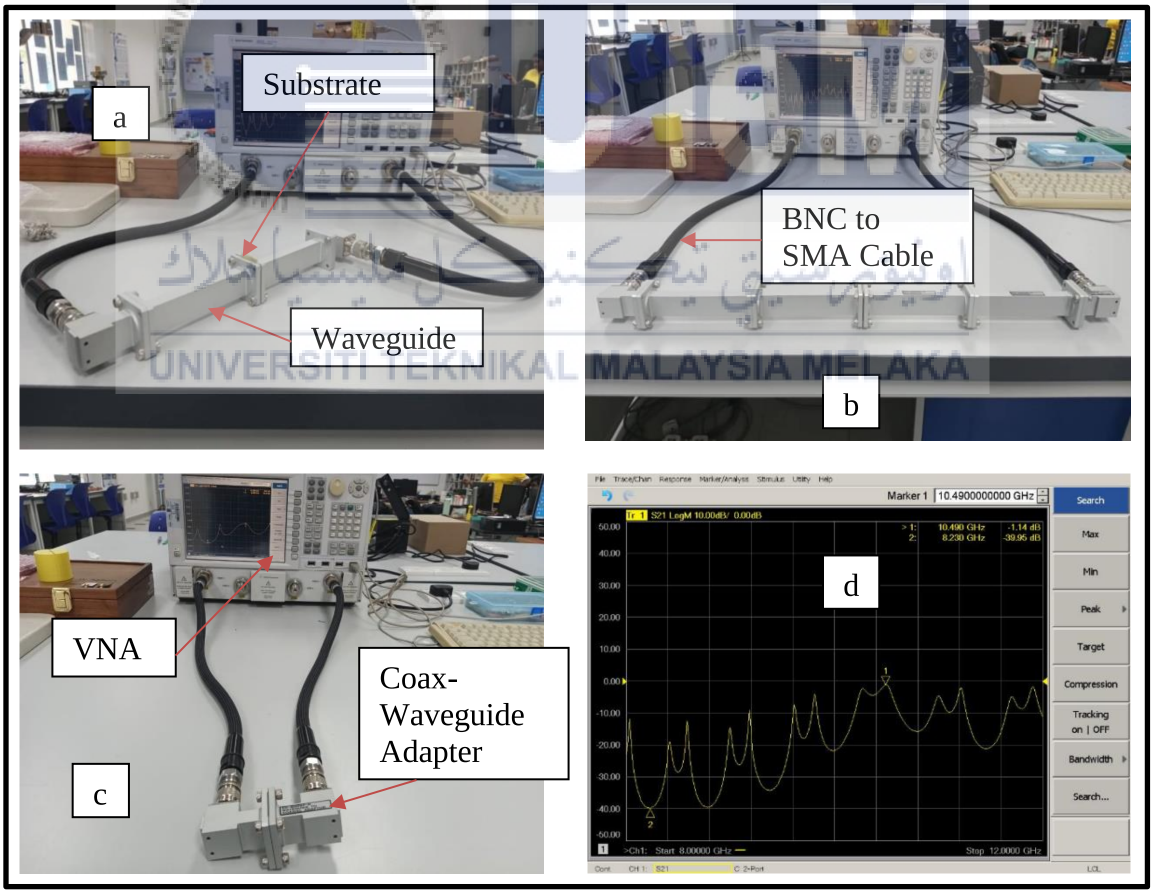


Figure 5.1 a)Two waveguide, b) 4 waveguide, c) Coaxial waveguide, d) The return Loss Measurement (S-Parameter)

5.2 Results Between Simulation and Measurement

In this section many different way of output has been observed. The section are separated into 5 parts. The main results are obtain from the s-parameter of S11 and S12.

5.2.1 Measurement Similarity between S11,S22 and S12,S21 for 2 material for only (Magnitude)

In this measurement below, Observed the similarity between the S-parameter for S11, S22 for S12, and S21. The values of it are similar. This is because the waveguide that we used is dual-ended and has 2 ports. In port 1st we observed the reflection of the material used FR-4 or Rogers while in the 2nd port, we observed the transmission which is from the reflection. Figure 5.2 shows the similarity for Magnitude and Figure 5.3 shows for Phase.

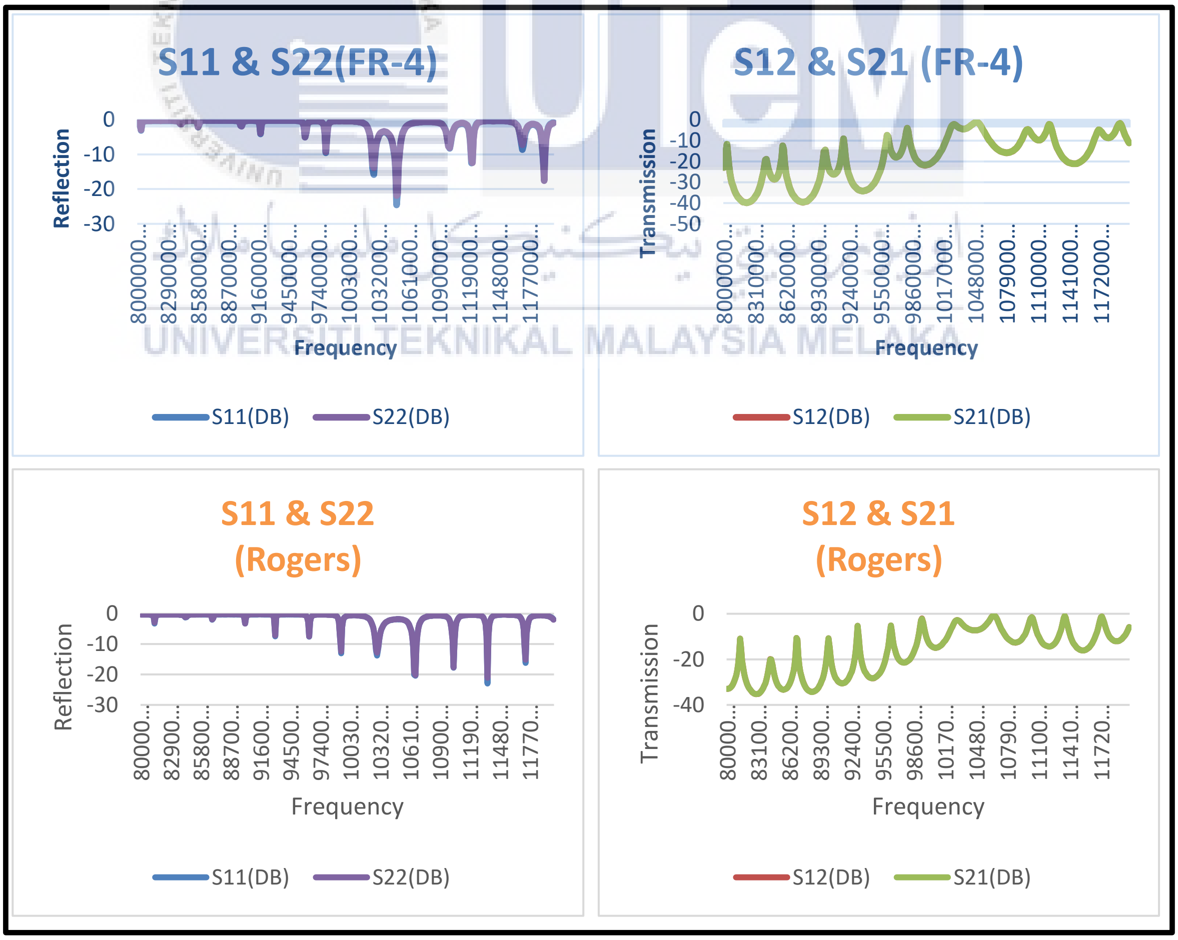


Figure 5.2 The Similarity between S-Parameter for Magnitude

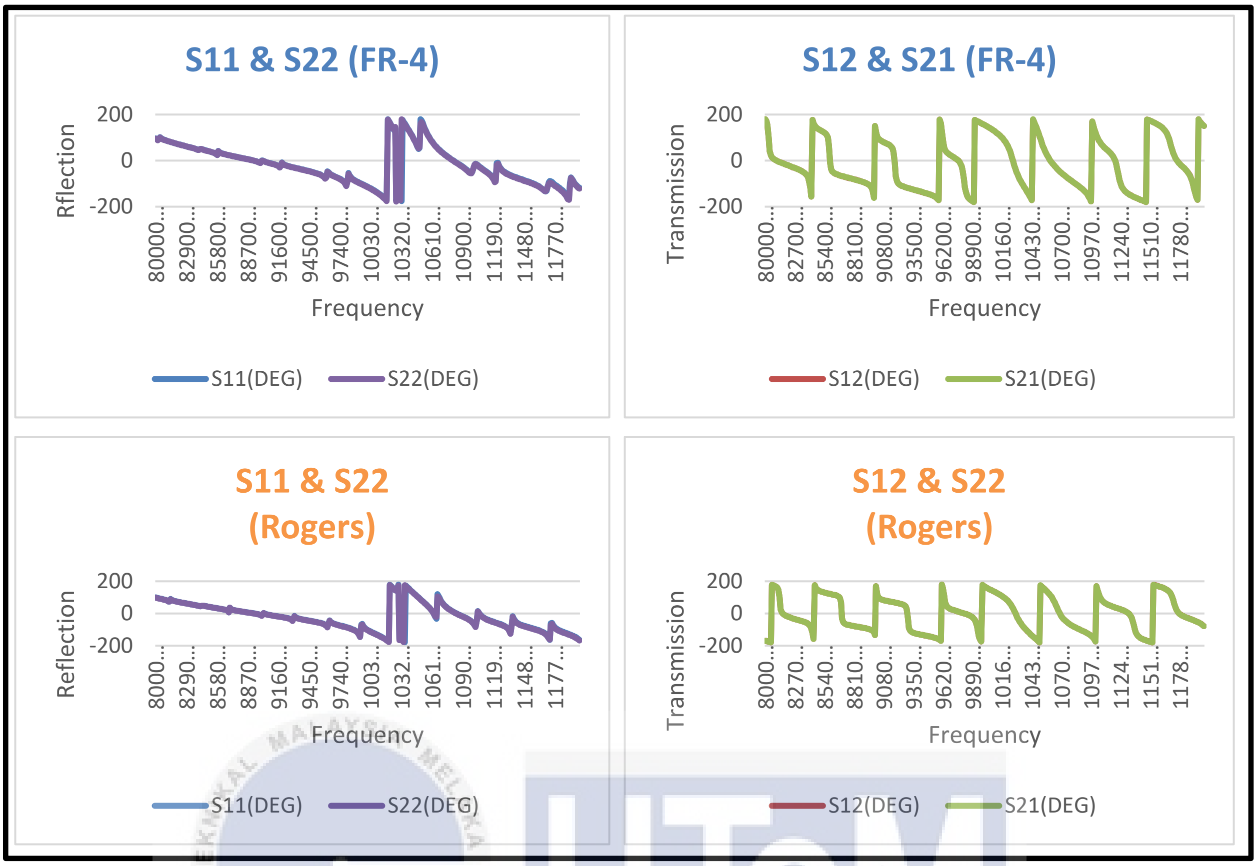


Figure 5.3 The Similarity between S-Parameter for Phase

The important factor in completing the above result is to show that S11 and S12 are parameters within the scattering matrix used in RF and microwave engineering to quantify the conduct of two-port devices. S11 represents the reflection coefficient at port 1, indicating how a whole lot of an incident wave is reflected, whilst S12 represents the transmission coefficient from port 1 to port 2, detailing how a lot of the signal is transmitted between ports. Both parameters are expressed as complicated numbers, imparting records on amplitude and segment relationships, and are fundamental for inspecting and designing circuits in applications like verbal exchange and radar systems.

5.2.2 Measurements Result for different length of waveguide (Magnitude & Phase)

In the measurement below, Observe the results that were obtained in measurement. The results that are obtained are converted into an Excel file to see the results in a clearer form. 3 different lengths of waveguides are done during measurement which is by 2 waveguides, 4 waveguides, and with only coaxial waveguide. The measurement was done using 2 different materials, Rogers and FR-4. Figure 5.4 shows the S-parameter of S11 and S12 for 2 waveguides, while Figure 5.5 shows the S-parameter of S11 and S12 for 4 waveguides and Figure 5.6 shows similar results when coaxial waveguide is used. The 3 figures observe the magnitude of the S-parameter while Figure 5.7-5.9 will be the same as above, but it shows the phase of the waveguide.

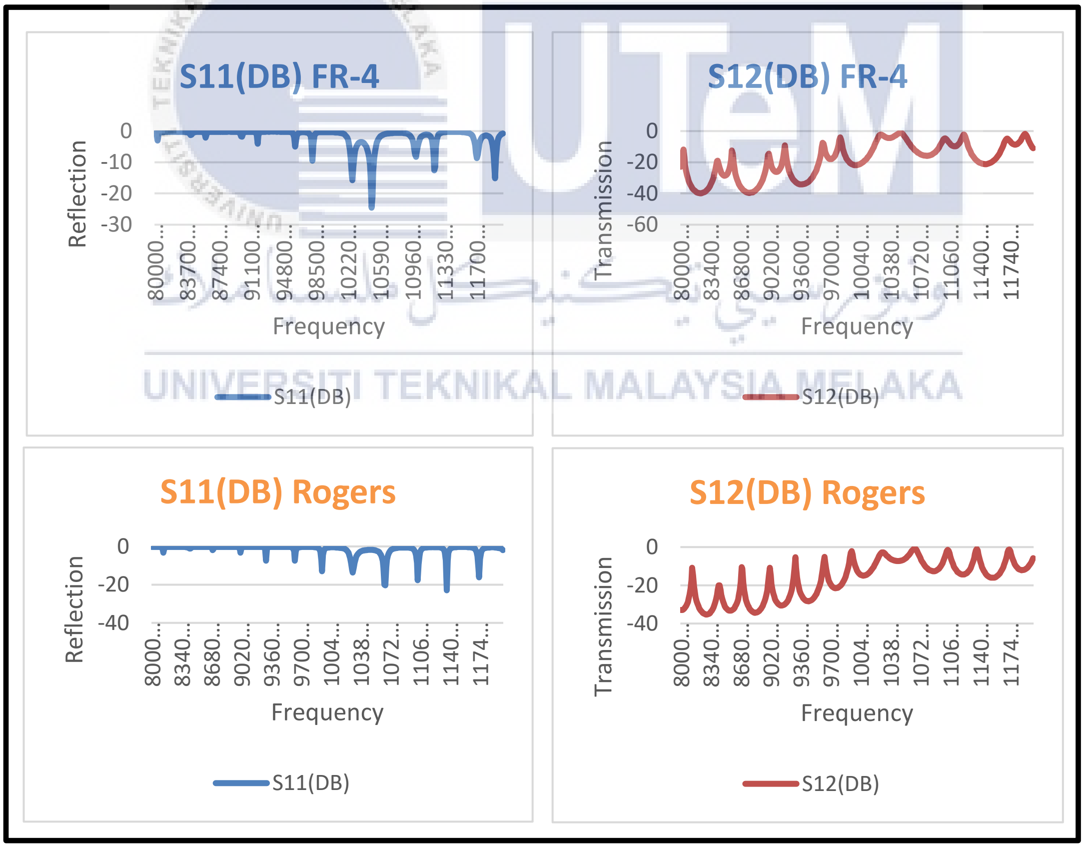


Figure 5.4 The Magnitude results of 2 Waveguide

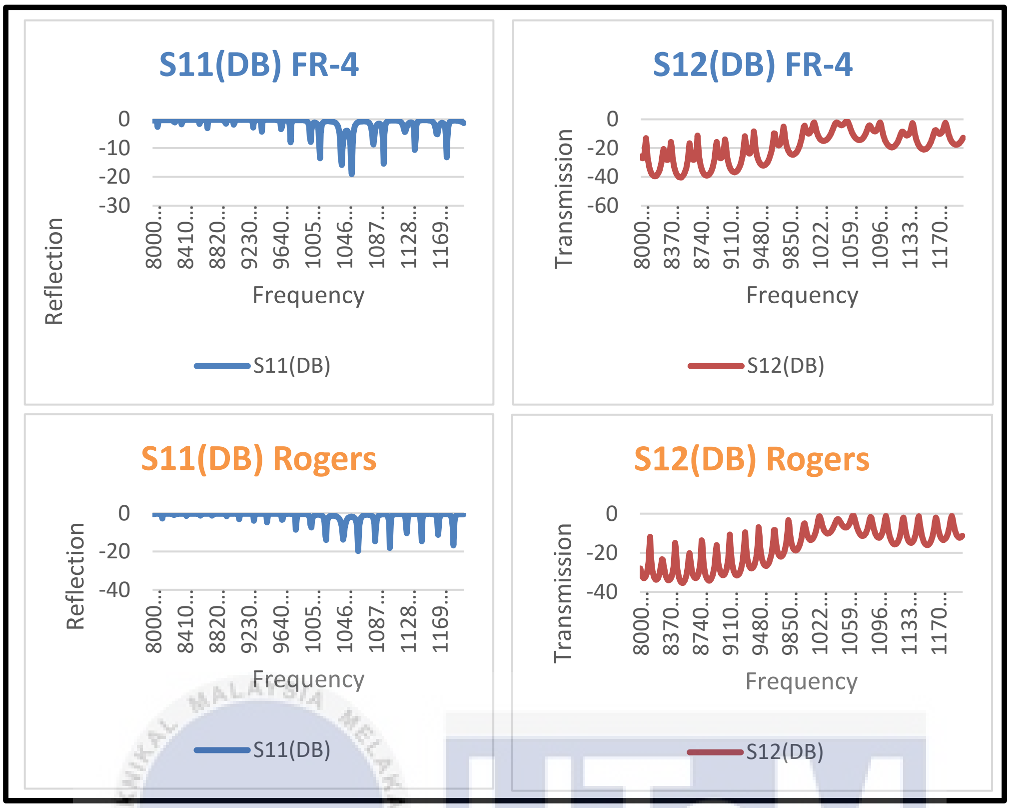


Figure 5.5 The Magnitude results of 4 Waveguide

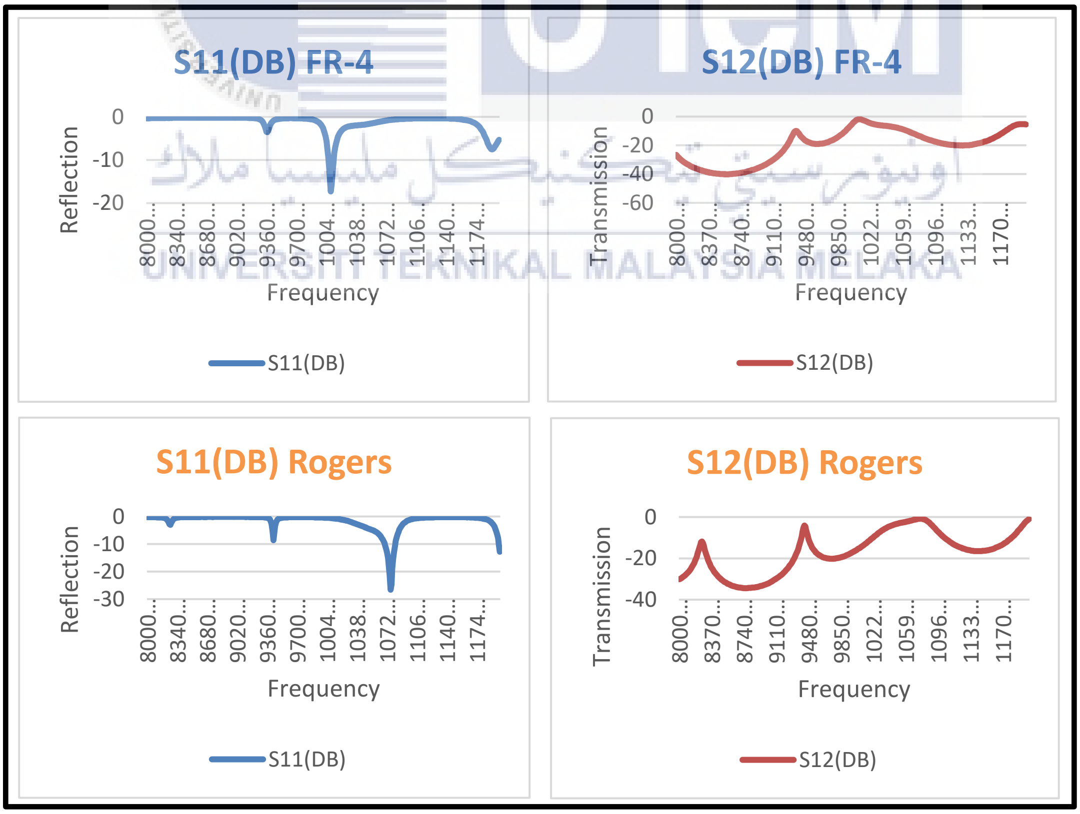


Figure 5.6 The Magnitude results of Coaxial Waveguide

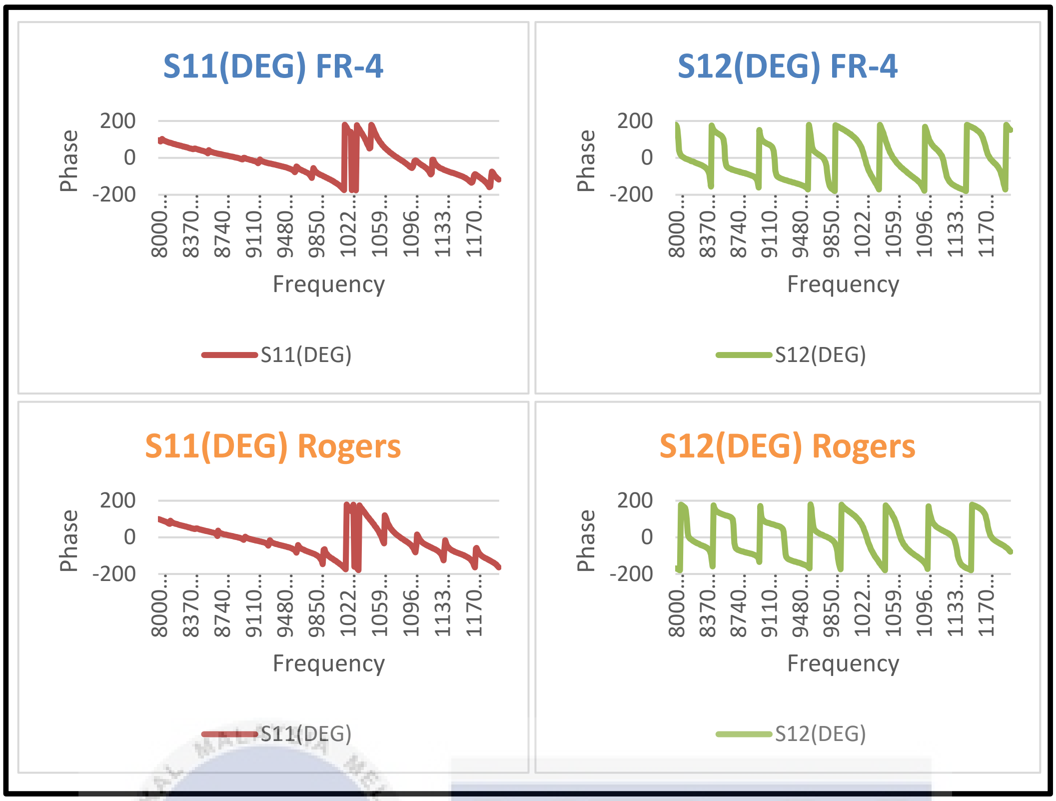


Figure 5.7 The Phase results of 2 Waveguide

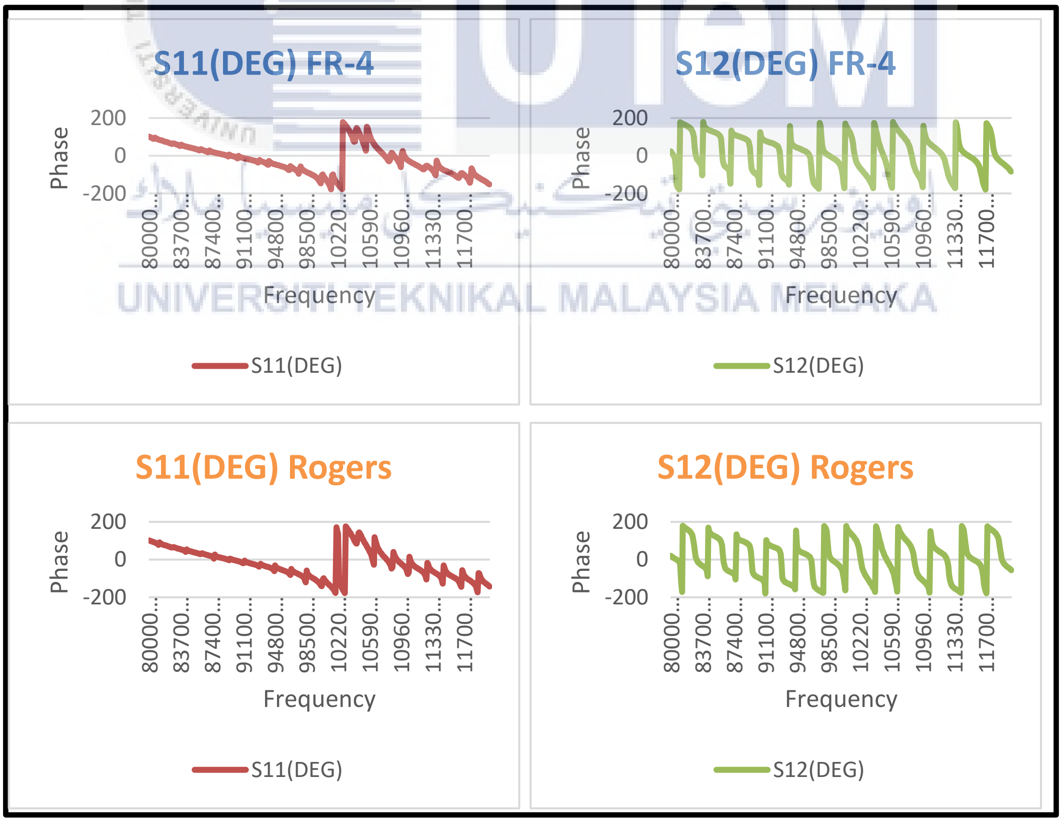


Figure 5.8 The Phase results of 4 Waveguide

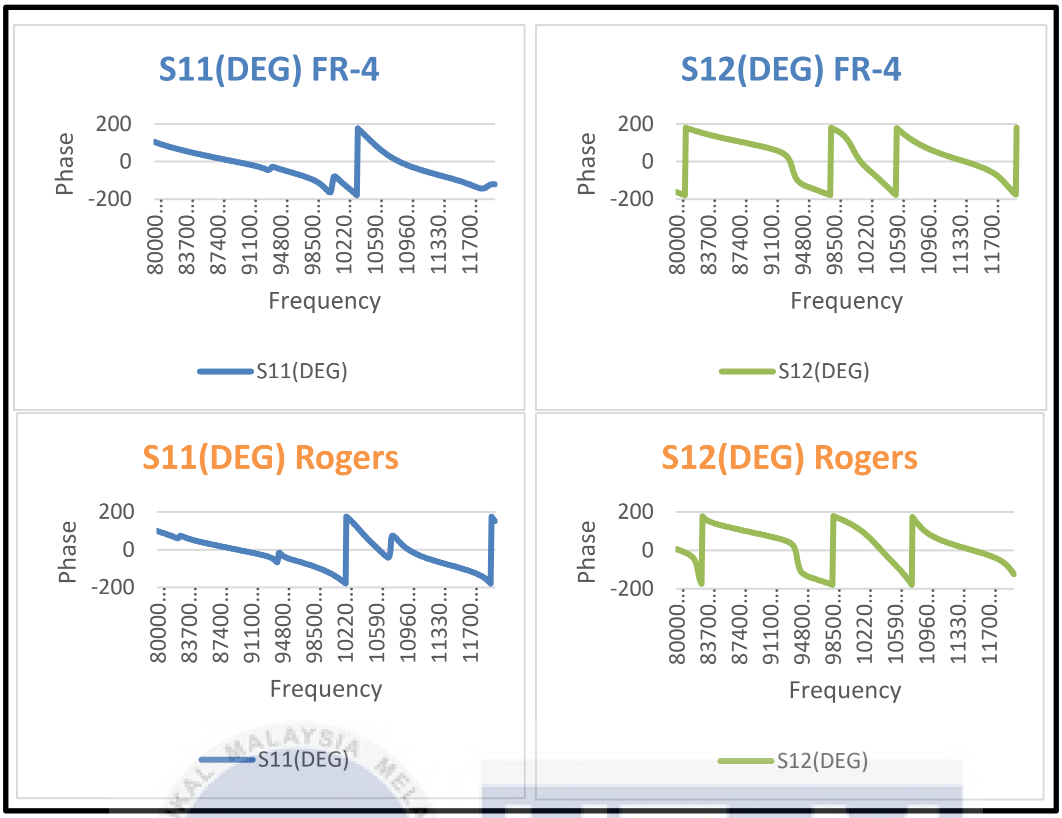


Figure 5.9 The phase results of Coaxial Waveguide

The magnitude and phase of S11 and S12 are quintessential components in characterizing the behaviour of two-port networks in RF and microwave engineering. The magnitude of S11 exhibits the extent of reflection at port 1, representing the ratio of the mirrored signal's amplitude to the incident signal's amplitude. Similarly, the magnitude of S12 expresses the percentage of the transmitted sign from port 1 to port 2 relative to the incident sign at port 1. These magnitudes furnish insights into sign attenuation, amplification, and transmission effectivity inside the network. Additionally, the phase records of S11 and S12 denote the section shifts happening between incident and reflected signals at port 1 and between incident signals at port 1 and transmitted signals at port 2.

5.2.3 Comparison between CST simulation and Hardware Measurement with the Permittivity (ɛr=4.3 and 2.2)

The measurements have been made by using two materials which are FR-4 and Rogers RT5880. The materials variable permittivity is for FR-4 is 4.3 and Rogers 2.2. By using the CST software the simulation result for 2.2 and 4.3 has been obtained. Below are the images to show the difference between the simulation and the measured value of the materials. Figure 5.10 shows the output waveform of S11 and S12 for 2 waveguide. Following by Figure 5.11, 4 waveguide and Figure 5.12, the coaxial-waveguide.

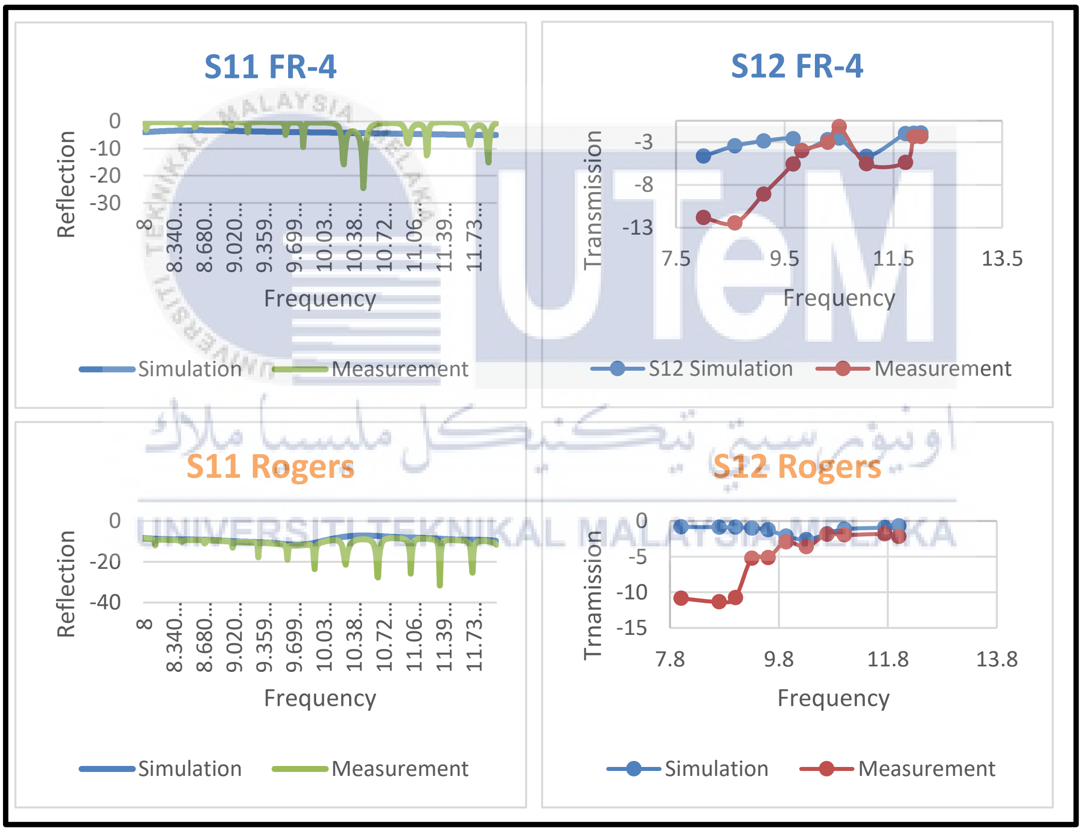


Figure 5.10 The output waveform of 2 Waveguide

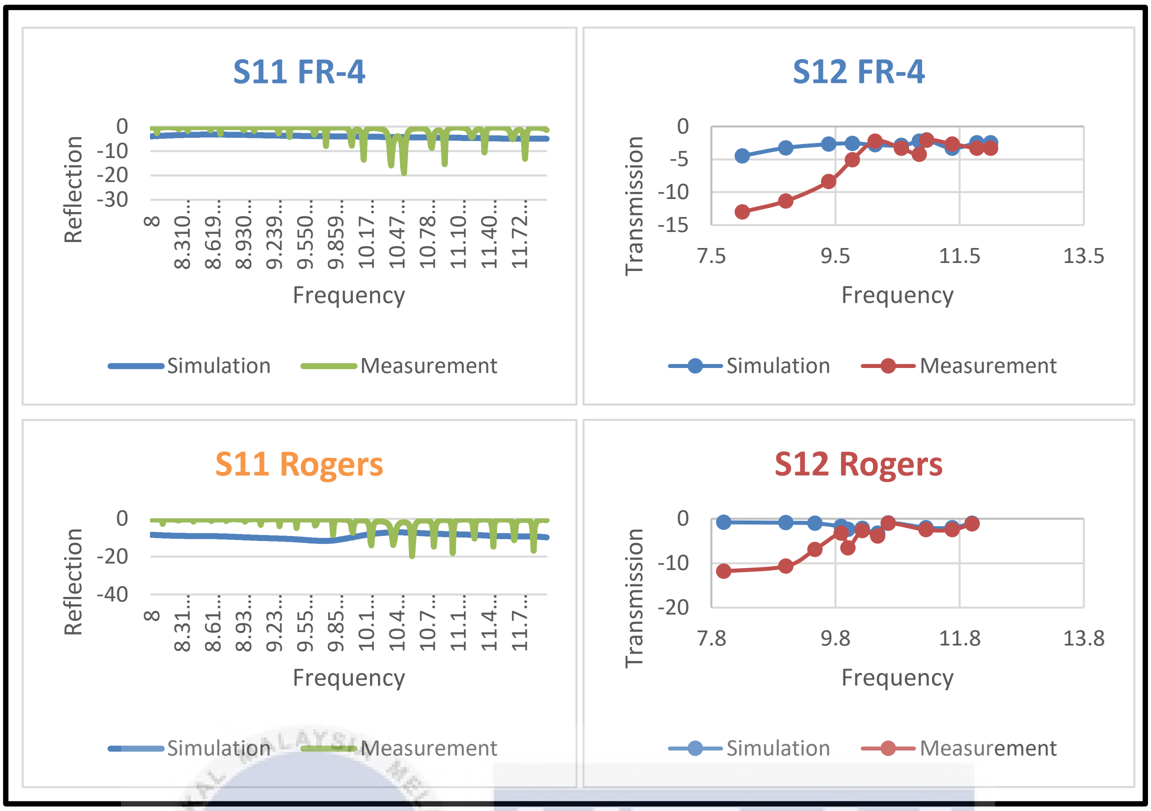


Figure 5.11 The output waveform of 4 Waveguide

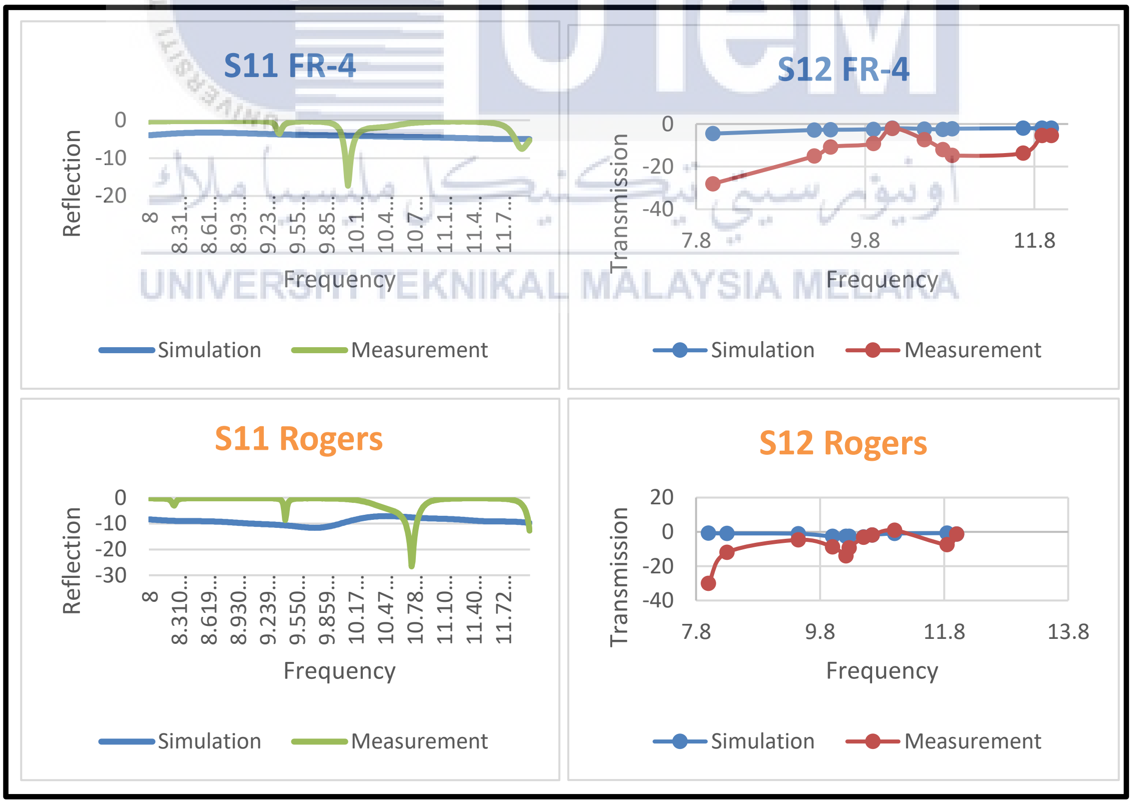


Figure 5.12 The output waveform of Coaxial Waveguide

The statistics which is proven above are a set of S11 and S12 simulation and dimension outcomes for dual-ended waveguides. S11 represents the energy reflected in the system, while S12 represents the electricity transmitted through the system. The simulations have been conducted for frequencies ranging from 8 GHz to 12 GHz. The material that has been measured is FR-4 with a permittivity of 4.3 and Rogers with a permittivity of 2.2. In Figure 5.10-12, we can examine that for each material FR-4 and Rogers the S11 which is the reflection has now not much distinction between them, however when it comes to the output it differs. The same goes for all of the other lengths of waveguides for S11. For S12, we can have a look at that, from 8GHZ the measured fee is far too much less than the simulation value.

Furthermore, following that when the frequency increases the number becomes almost equal to the simulation. Simulation and size range in their necessary techniques to appreciate and examine phenomena. Simulation entails creating theoretical models to predict system behaviour in controlled, frequently idealized environments with the use of mathematical representations. It is predictive and allows for exploring eventualities besides direct real-world interaction. On the other hand, size includes the direct statement and quantification of real-world data, providing empirical insights into the proper nation or conduct of a system. Measurements capture inherent variability and uncertainties in the system, offering verification or validation for theoretical models or simulations. In essence, simulation is a synthetic, model-based approach, whilst measurement deals with direct, real-world observations and records collection.

5.2.4 Comparison between FR-4 vs Rogers material with 3 different length of Waveguide (Magnitude only)

In this section, we observed the different results between FR-4 and Rogers material. By this, we can observe which material or permittivity has lesser return loss. The same method has been used to obtain the measurement. In Figure 5.13 we can observe the difference between FR-4 and Rogers material by using 2 waveguides. Following Figure 5.14 – 15, the only changes are 2 waveguides and the coaxial waveguide.

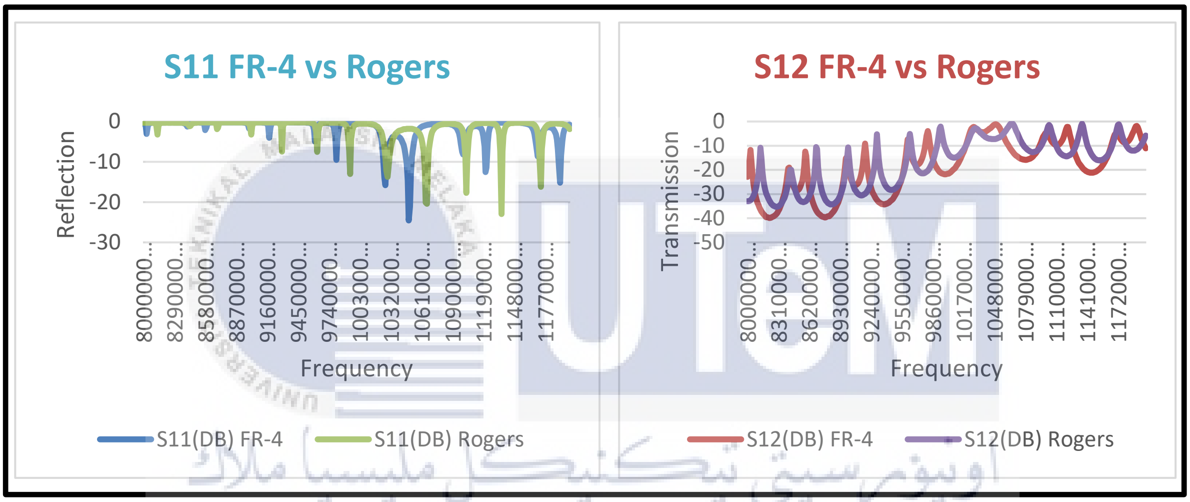


Figure 5.13 The difference between FR-4 and Rogers for 2 Waveguide

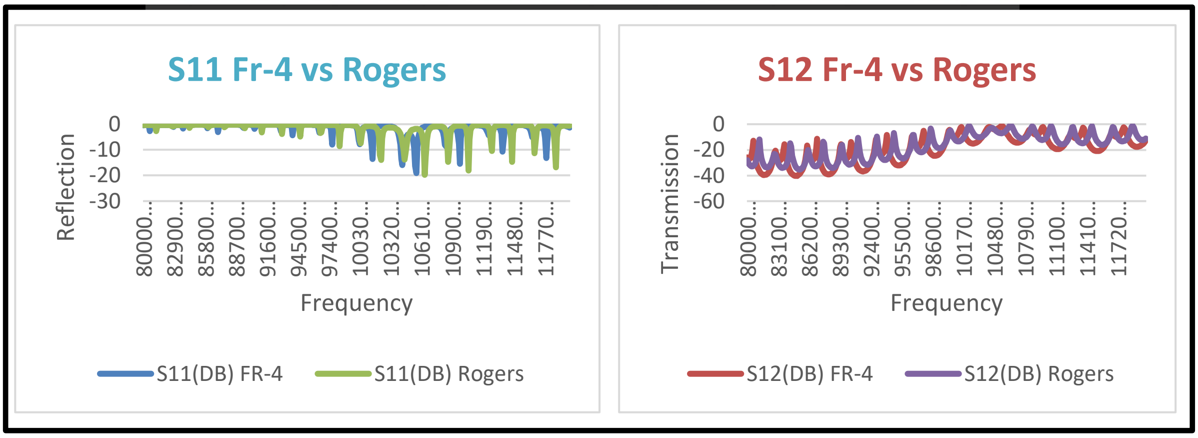


Figure 5.14 The difference between FR-4 and Rogers for 4 Waveguide

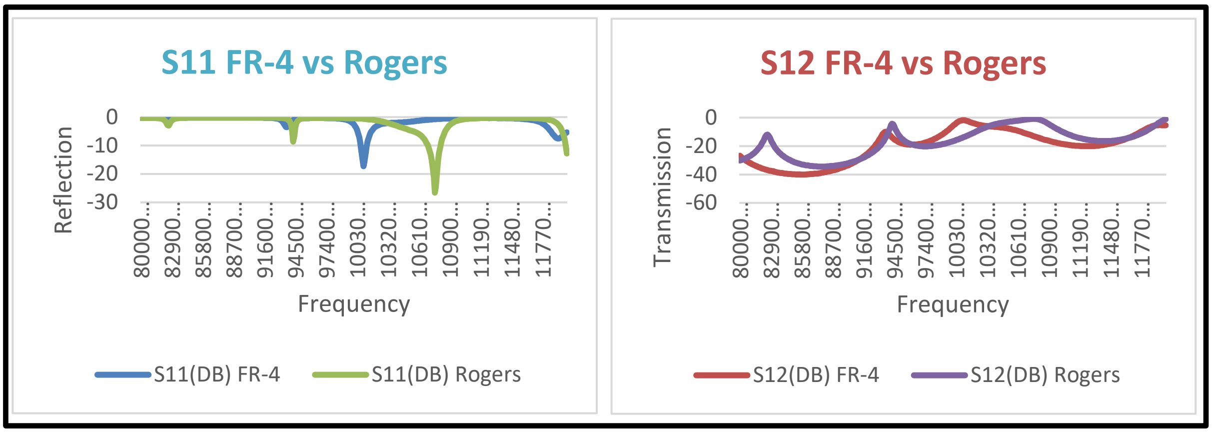


Figure 5.15 The difference between FR-4 and Rogers for Coaxial Waveguide

The established description for the material, FR-4 is a standard, least expensive fabric suitable for general-purpose PCBs, whilst Rogers substances are chosen for specialized applications where high-frequency performance, low sign loss, and secure dielectric properties are essential. The fabric FR-4 has a relative permittivity of 4.3. It typically signifies a reasonable to excessive degree of electrical power storage capability. On the other hand, rogers has a relative permittivity of 2.2 indicating a decreased dielectric constant. Rogers materials are often chosen when minimizing the impact of the dielectric on the electric-powered field is crucial, particularly in functions the place retaining signal integrity and lowering signal loss are priorities, such as in high-frequency or microwave circuits. When measuring variable permittivity, the preference between FR-4 and Rogers relies upon the unique necessities of your application. If a fee is a giant consideration, and your utility operates at decreased frequencies, FR-4 might also be a suitable and cost-effective option. However, in the above figure from 5.13-16, we can conclude that the return loss for both materials is nearly similar. By this, we can see that the measurements taken in the lab session used to be successful.

5.2.5 The measurement of FR4 and Rogers for only S12 Magnitude

In this section, Observe only the magnitude of the S12 parameter. The reason only S12 is observed is because S12 acts as the transmission for the whole system. By this definition, S12 is the output waveform of the diagram. The diagram has been observed from the 3 different lengths of waveguide, by using 2 materials which are FR-4 and Rogers RT5880. In Figure 5.17 observes the S12 parameter for 2 waveguide, 4 waveguide and Coaxial waveguide by using the FR-4 material while Figure 5.18 shows the same but using different material which is Rogers RT 5880.

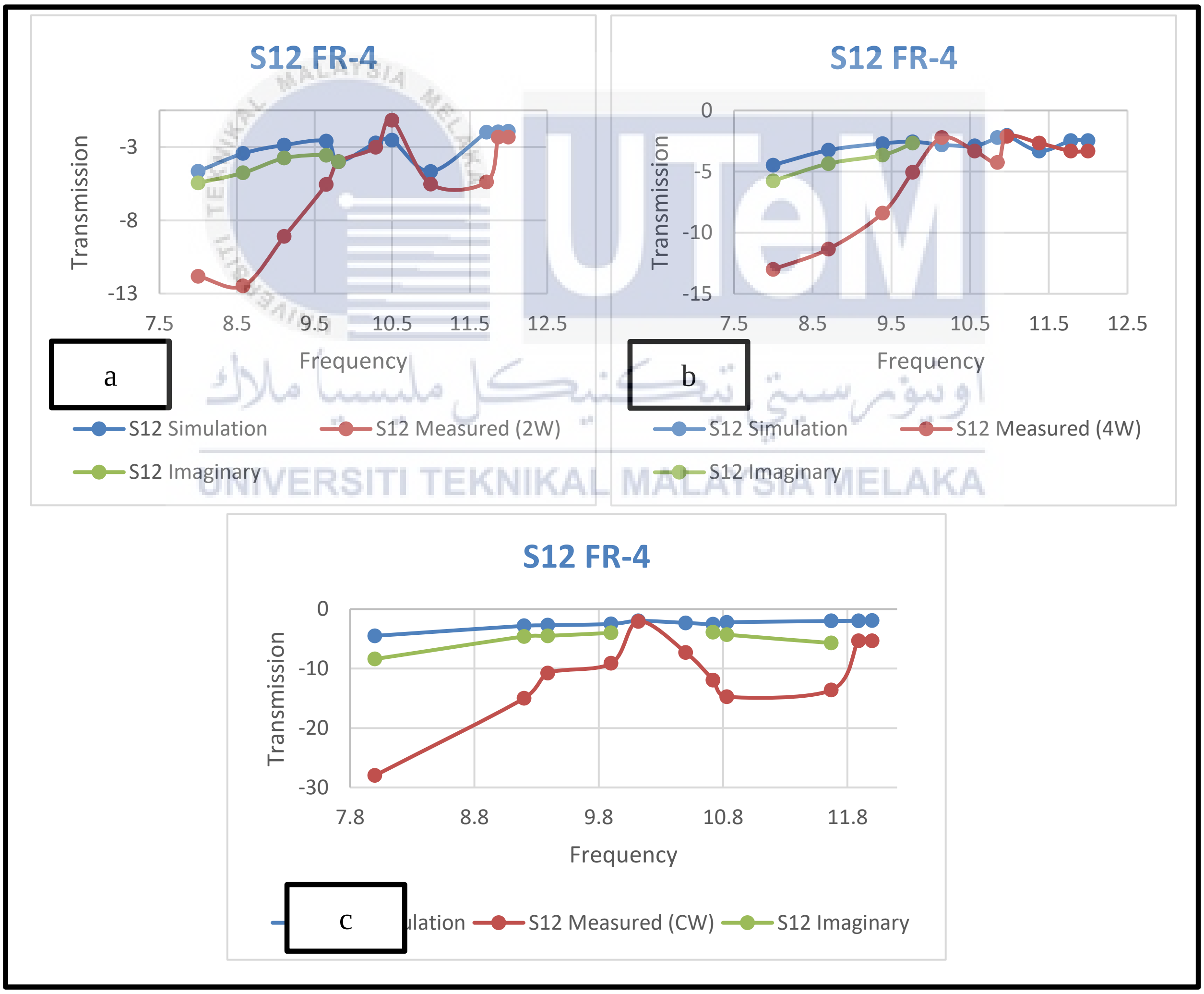


Figure 5.16 The FR-4 Results a) 2 Waveguide, b) 4 Waveguide, c) Coaxial Waveguide

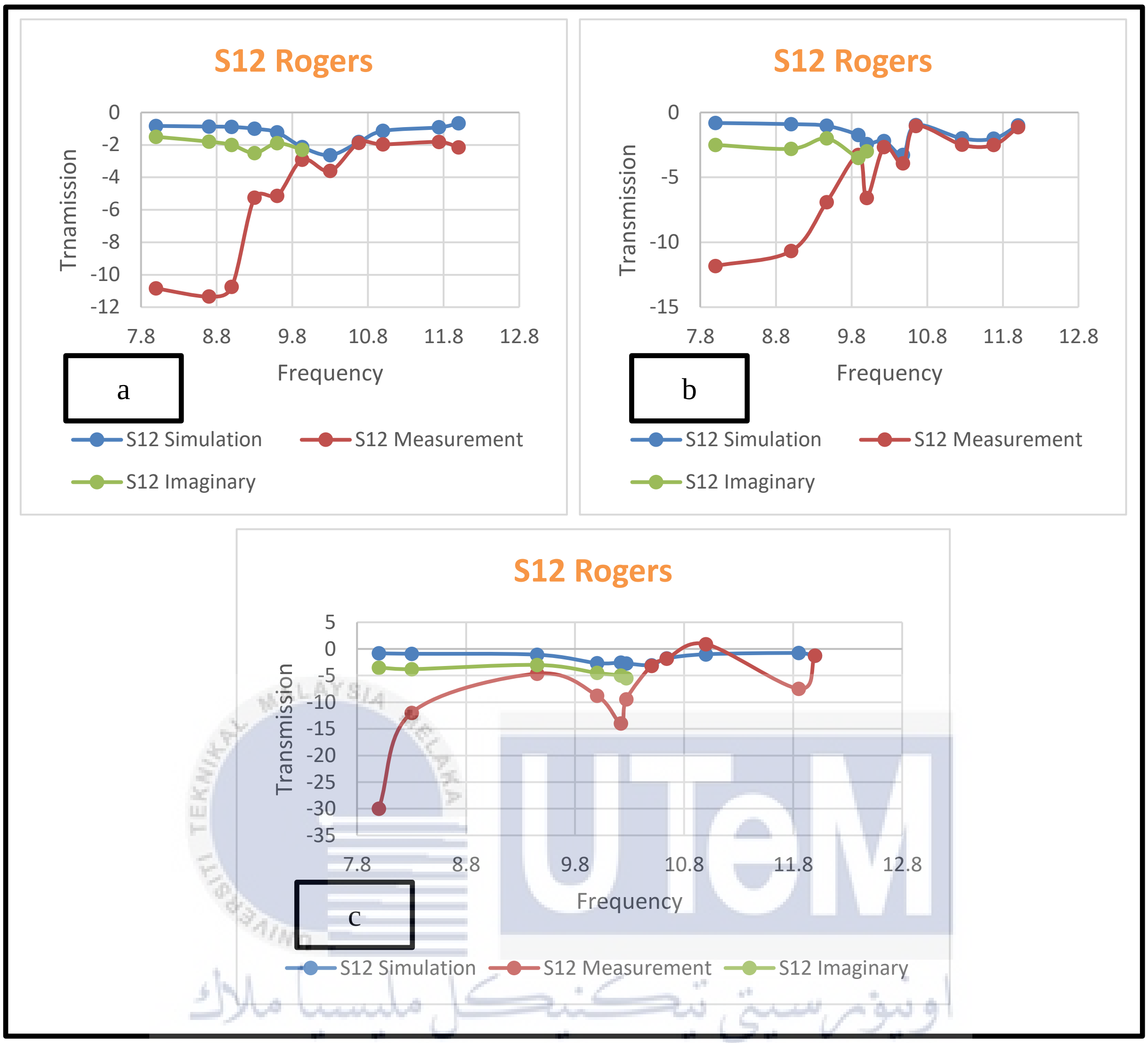


Figure 5.17 The Rogers Results a) 2 Waveguide, b) 4 Waveguide, c) Coaxial Waveguide

Figure 5.16, includes S12 Simulation and S12 Measured values for three specific lengths of waveguides FR-4 substances (FR-4 (2 waveguides), FR-4 (4 waveguides), and FR-4 (Coaxial waveguide)) at a range of frequencies. A contrast reveals variations in simulated and measured responses. For instance, at 8GHZ for simulation, the S12 values range from -4.65 to -4.5, whilst corresponding S12 Measured values vary from -11.82 to -28. These variations persist throughout frequencies, indicating discrepancies in the simulation accuracy. Additionally, evaluating the three lengths of waveguide for the FR-4 substances at specific frequencies showcases how their length affects the simulated results.

Analyzing these versions aids in the perception of the overall performance of the simulation model across exclusive materials and frequencies, imparting insights for double adjustments or upgrades in the simulation approach.

Then in Figure 5.17, The provided information consists of S12 Simulation and S12 Measurement values for three lengths of waveguide for Rogers materials (Rogers (2 waveguide), Rogers (4 waveguide), and Rogers (coaxial waveguide)) at a range of frequencies. An assessment between the simulation and size values displays traits and differences across the frequencies. For instance, at 8 GHz, the S12 Simulation values range from -0.83 to -0.82, while the corresponding S12 Measurement values range from -10.85 to -30.00. Similar variations persist throughout the dataset, showcasing the discrepancy between simulated and measured responses.

Examining particular frequencies highlights how the three lengths of waveguides behave in terms of S12 Simulation and S12 Measurement. At 9.6 GHz, for example, Rogers (coaxial waveguide) shows a large deviation between simulation and dimension (-2.71 vs. -9.43) compared to Rogers (2 waveguide) and Rogers (4 waveguide). Analyzing such variations aids in understanding the accuracy of the simulation model for each material and frequency, presenting precious insights for possible adjustments or improvements. In conclusion, all the figure at the starting point has a lot of differences it is because when doing the measurement process, the cable, VNA, the waveguide, or many other factors cause it to have high return loss. Hatching, process can also be included in this part. But when the frequency rises all of the parameters have similar points which proves that our measurement and simulation are almost the same and the experiment was a success.

5.3 Summary

In Chapter 5 of the thesis, the dimension strategies and effects of a dual-ended waveguide diagram experiment are discussed. Three editions of the experiment have been conducted by changing the size of the waveguide: using 2 waveguides, four waveguides, and a coaxial waveguide. The results had been analysed in phrases of S-parameters (S11 and S12), focusing on both magnitude and phase. The similarity between S11, S22, and S12, S21 for two substances (FR-4 and Rogers) used to be examined. Measurements were further conducted for exceptional lengths of waveguides, and an evaluation between CST simulation and hardware dimension was presented, thinking about exclusive permittivity values. Additionally, a contrast between FR-4 and Rogers substances was once made, highlighting return loss differences. The chapter concluded with a commentary on the magnitude of S12 for FR-4 and Rogers throughout a variety of lengths of waveguides, revealing similarities as the frequency increased. The writer emphasized that no matter the preliminary differences, the simulation and dimension effects converged at greater frequencies, validating the accuracy of the experiment.

CHAPTER 6

CONCLUSION AND RECOMMENDATIONS

6.1 Conclusion

In conclusion, the provided data highlights the value of S11 and S12 parameters in RF and microwave engineering for characterizing the conduct of two-port devices. S11 displays the reflection coefficient at port 1, while S12 represents the transmission coefficient from port 1 to port 2 The magnitude and phase values of these parameters provide essential insights into sign attenuation, amplification, and transmission effectivity inside the network. The study presents simulation and dimension outcomes for dual-ended waveguides made of FR-4 and Rogers materials, comparing S11 and S12 values throughout exceptional frequencies. Notable variations between simulation and measurement outcomes are observed, specially at decrease frequencies. However, as the frequency increases, the measured values converge with the simulation results, suggesting successful experiments.

The discussion on material houses emphasizes the suitability of FR-4 for general-purpose PCBs and Rogers materials for specialised functions requiring high-frequency performance and low sign loss. Return loss measurements indicate similar performance for both materials, affirming the success of the laboratory measurements. The evaluation of S12 values for distinct lengths of waveguides similarly exhibits variants between simulated and measured responses. While discrepancies exist, specifically at decrease frequencies, the alignment of consequences as frequencies amplify suggests the normal success and accuracy of the measurement process.

In summary, the find out about underscores the significance of thinking about both simulation and size methods in RF and microwave engineering. While simulations grant predictive fashions in managed environments, measurements offer real-world observations with inherent variability. The determined variations at decrease frequencies highlight practicable areas for improvement in simulation models or size procedures. However, the convergence of outcomes at greater frequencies validates the success of the experimental setup, imparting precious insights for future adjustments or enhancements in the area of RF and microwave engineering.

6.2 Recommendations

The following areas may be covered in upcoming work toward the creation of a dual-ended waveguide dielectric characteristics measurement system stated in the below paragraph.

i) Investigate techniques to increase the accuracy of measurements of dielectric characteristics. This can entail improving calibration practices, lowering measurement errors, and taking into account any potential interference or noise sources.

ii) Broaden the frequency range as in, Increase the system's frequency range to span a larger spectrum. Extending the measuring range would permit through characterization of materials across various frequency bands because dielectric characteristics can change dramatically with frequency.

iii) Analyse the relationship between temperature and a material's dielectric characteristics and add temperature compensating methods into your measurement system. This would be useful for materials like polymers or ceramics that exhibit temperature-dependent dielectric behaviour.

iv) Miniaturisation and Portability. Look for ways to make the measurement system smaller and more portable. For measurements in the field or in applications with limited area, this would make it more useful.

v) Investigate how the measurement system can be integrated with automation technologies, such as conveyor systems or robotics. This would make measurements more effective and high-throughput, making it appropriate for industrial applications.

6.3 Project Potential

This undertaking explores the characterization of two-port units in RF and microwave engineering, focusing on parameters S11 and S12. The goals consist of a dual-ended waveguide analysis, a cloth contrast between FR-4 and Rogers, and an integration of simulation and measurement tactics for comprehensive insights. Firstly, S11 and S12 analysis of the Initial findings divulge superb differences between simulated and measured S11 and S12 values at lower frequencies. However, as frequency increases, convergence is observed, maintaining the accuracy of the experimental setup. This prompts further exploration into attainable changes in simulation fashions or dimension procedures.

After that, Material Comparison is achieved to study FR-4 and Rogers materials, emphasizing their distinct properties. FR-4, low-priced and appropriate for general-purpose PCBs, contrasts with Rogers, preferred for high-frequency applications. Return loss measurements, particularly similar for each materials, validate the success of laboratory measurements.

Furthermore, Simulation-Measurement Integration is that the assignment effectively integrates simulation and size approaches, highlighting the significance of considering both for a comprehensive analysis. The convergence of results at higher frequencies validates the experimental setup's accuracy, bettering the reliability and applicability of the findings. Then, An insightful examination of S12 values throughout frequencies unveils frequency-dependent behaviour, presenting precious data on gadget overall performance variants with signal frequency. The located differences at decrease frequencies information possible enhancements in simulation fashions or dimension procedures.

Next, The project's findings provide huge implications for RF and microwave engineering. Material insights resource engineers in most efficient cloth selection. S11 and S12 analyses make a contribution to circuit optimization for conversation and radar systems. The practical applicability of the consequences in enterprise underscores the value of combining theoretical fashions with real-world observations.

In conclusion, this challenge represents a splendid stride in advancing RF and microwave engineering. The found discrepancies at decrease frequencies instant similarly exploration, while the convergence at greater frequencies validates the experimental success. The integration of simulation and size tactics enhances the study's robustness, imparting valuable insights for persevered refinement in RF and microwave engineering practices.

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APPENDICES

Appendix A Gantt Chart For Final Year Project 1

ACTIVITY (FYP 1)	WEEK													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Meet with supervisor	🟧	🟧				🟧		🟧		🟧	🟧		🟧	
Research literature review & gather information		🟧	🟧	🟧		🟧								
Submission of logbook progress						🟧						🟧		
Proposal writing	🟧	🟧												
Report writing			🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	
Submission of draft report												🟧		
Submission of report													🟧	🟧
Preparation for presentation												🟧	🟧	

Appendix B Gantt Chart For Final Year Project 2

ACTIVITY (FYP 2)	WEEK													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Meet with supervisor	🟥	🟥	🟥	🟥	🟥	🟥	🟧	🟥	🟥	🟥	🟥	🟥	🟥	🟥
Preparing Multiple Simulation in CST software		🟥	🟥	🟥	🟥	🟥	🟧	🟥	🟥	🟥	🟥			
Submission of logbook progress						🟥	🟧					🟥		
Collecting Material for the project			🟥	🟥	🟥	🟥	🟧	🟥	🟥					
Fabricating Process							🟧	🟥	🟥	🟥				
Report writing			🟥	🟥	🟥	🟥	🟧	🟥	🟥	🟥	🟥	🟥	🟥	
Measuring Process							🟧				🟥	🟥		
Compare the results							🟧				🟥	🟥	🟥	
Submission of draft report							🟧					🟥	🟥	
Submission of report							🟧							🟥
Preparation for presentation							🟧							🟥

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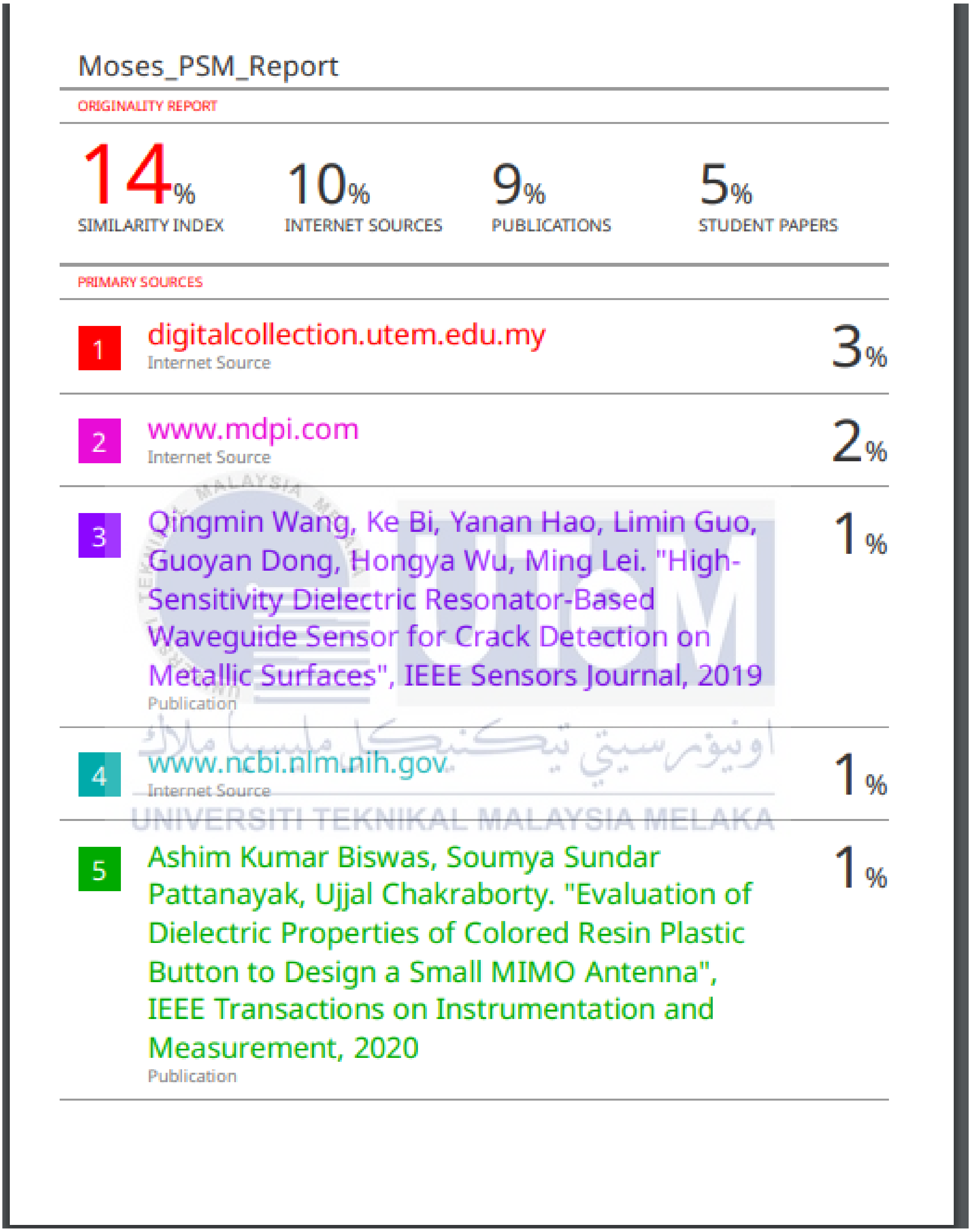

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