# DEVELOPMENT AND CHARACTERIZATION OF A TISSUE EQUIVALENT PHANTOM FOR MICROWAVE APPLICATIONS (500 MHZ – 1 GHZ)

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UNIVERSITI TEKNIKAL MALAYSIA MELAKA

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

**Faculty of Electronic and Computer Technology and Engineering**
**Universiti Teknikal Malaysia Melaka**

**2024**

**UNIVERSITI TEKNIKAL MALAYSIA MELAKA**
FAKULTI TEKNOLOGI DAN KEJURUTERAAN ELEKTRONIK DAN KOMPUTER

**BORANG PENGESAHAN STATUS LAPORAN**
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Tajuk Projek : Development and Characterization of a Tissue Equivalent Phantom for Microwave Applications (500 MHz – 1 GHz).

Sesi Pengajian : 2023/2024

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# DEDICATION

This thesis is dedicated to my supervisor, Ts. Dr. Noor Badariah binti Asan, whose continuous support, sacrifices, and encouragement have served as my greatest source of motivation. Your faith in my ability has motivated my determination to achieve my goal. Thank you for being my pillars of strength along this journey.

# ABSTRACT

The development of biomedical applications depends heavily on tissue-mimicking phantoms, which are of tremendous interest. Humans have been put at risk and animals have been killed because biological tissues are employed in therapeutic experiments. More than 110 million animals, including mice, rats, frogs, dogs, cats, rabbits, hamsters, guinea pigs, primates, fish, and birds, are killed every year in laboratories in the United States for biology classes, medical training, curiosity-driven experiments, and chemical, drug, food, and cosmetics testing. The aim of this project is to investigate and develop Tissue Equivalent Phantom materials for microwave applications (500 MHz – 1 GHz). The literature review will also provide insight into the properties required for tissue phantom materials to simulate biological tissues accurately. Based on the findings of the literature review, tissue equivalent phantom materials will be developed and characterized to determine their electrical and physical properties and will be evaluated for their ability to simulate biological tissues and their suitability for use in microwave applications. This project's outcome will be the development of tissue equivalent phantom materials that can be used as a standard for testing and optimizing microwave devices and systems. These tissue equivalent phantom materials will be useful for researchers and medical device manufacturers to

evaluate the performance and safety of microwave systems before using them in clinical applications.

# ABSTRAK

*Perkembangan aplikasi bioperubatan sangat bergantung pada tisu tiruan, yang sangat menarik. Manusia telah diletakkan pada risiko dan haiwan telah dibunuh kerana tisu biologi digunakan dalam eksperimen terapeutik. Lebih daripada 110 juta haiwan, termasuk tikus, katak, anjing, kucing, arnab, hamster, guinea pig, primata, ikan, dan burung, dibunuh setiap tahun di makmal di Amerika Syarikat untuk kelas biologi, latihan perubatan, eksperimen yang didorong oleh rasa ingin tahu, dan ujian kimia, dadah, makanan dan kosmetik. Matlamat projek ini adalah untuk menyiasat dan membangunkan bahan Phantom Setara Tisu untuk aplikasi gelombang mikro (500 MHz – 1 GHz). Kajian literatur juga akan memberikan gambaran tentang sifat yang diperlukan untuk bahan tisu fantom untuk mensimulasikan tisu biologi dengan tepat. Berdasarkan penemuan kajian literatur, bahan tisu fantom akan dibangunkan dan dicirikan untuk menentukan sifat elektrik dan fizikalnya dan akan dinilai untuk keupayaan mereka untuk mensimulasikan tisu biologi dan kesesuaiannya untuk digunakan dalam aplikasi gelombang mikro.*

# ACKNOWLEDGEMENTS

The work presented in this thesis would not have been accomplished without the guidance of a handful of important people. I would like to express my gratitude to my supervisor, Ts. Dr. Noor Badariah binti Asan, for her constant assistance, encouragement, and immense knowledge during the research. My supervisor was a true guide throughout the semester. I am grateful for the opportunity to be supervised by her for my final year project.

Beyond that, I want to thank and acknowledge my professors and panels, whose advice, encouragement, and support have been invaluable to me during this project. I would also like to thank them for their feedback and ideas on how to improve my research procedure and project finalization. In addition, students from master's and doctoral programmed who helped me along the way.

Furthermore, I would like to convey my gratitude to Universiti Teknikal Malaysia Melaka for providing me with an excellent environment and infrastructure in which to pursue my studies and complete my final year project. I am also grateful to the participants who kindly contributed their time and insights to this study. Finally, but not least, I dedicate this thesis to my family and loved ones, who have always believed in me and provided me with strength and motivation.

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# LIST OF SYMBOLS AND ABBREVIATIONS

| | | |
|---|---|---|
| DI | : | Deionized water |
| HEC | : | Hydroxyethyl Cellulose |
| 3D | : | Three-dimensional |
| AWA | : | Animal Welfare Act |
| CT | : | Computed Tomography |
| MUT | : | Material Under Test |
| TEP | : | Tissue Equivalent Phantom |
| PPE | : | Personal Protective Equipment |
| UV | : | Ultraviolet |
| $\varepsilon''_r$ | : | The imaginary part of relative permittivity |
| $\varepsilon'_r$ | : | The real part of relative permittivity |
| GHz | : | Gigahertz |
| Hz | : | Hertz |
| MHz | : | Megahertz |
| $\tan\delta$ | : | The loss tangent of dielectric properties |
| MICS | : | Medical Implant Communication System |
| ISM | : | Industrial, Scientific, and Medical |
| PE | : | Percentage Error |

# LIST OF APPENDICES

# CHAPTER 1

# INTRODUCTION



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## 1.1 Overview

The phantoms must mimic the electromagnetic characteristics of human tissues in the frequency range of interest in order to be realistic. Since water is the primary component of most biological tissues, using water as the primary component of a phantom tends to ensure a good approximation to the electromagnetic behavior of the envisioned biological tissue. Water properties can be adjusted to fit those of the intended tissue by adding certain components to the water according to a recipe. One issue with a water-based phantom is its conservation, as some evaporation is unavoidable. To reduce water loss and increase the phantom's lifespan, it must be properly maintained and handled. Tissue-equivalent phantoms are used in medicine for research, test, development, and figure out various biomedical devices by mimicking human biological tissues. To accurately mimic human tissue with an exact equivalent, an accurate artificial phantom with three primary qualities is required: realistic anatomy, accurate dielectric accuracy, and long shelf life. The project's aim for the future is to fabricate semi-solid skin, fat, and muscle phantoms for biomedical applications. According to [1], the dielectric properties of various tissues in the human body, such as relative permittivity and conductivity, fluctuate substantially depending on their kind. The characteristics also vary greatly depending on the operation frequency.

## 1.2 Problem statement

To evaluate the efficacy of certain vaccinations and medications for chronic illnesses and viruses, both humans and animals are used in major clinical trials. According to, the United States kills more than 100 million animals annually. The animals that have been used in research are handled like disposable pieces of lab equipment. According to some estimates, up to 800 laboratories in the United States operate solely with mice, rats, and other animals whose use is mostly uncontrolled, and exempt from government regulations and inspections. Even in fully compliant facilities, protected animals may still be burned, shocked, poisoned, secluded, malnourished, confined forcibly, drug addicted, and brain damaged [1]. Researchers discovered that applying medicinal therapies created for animals to humans was uncommon and advised patients and doctors to tread cautiously when applying significant findings from animal research to the treatment of humans. In addition, millions of Americans volunteer every year to participate as human subjects in medical studies that contrast new and old treatments. The recently founded device emits high frequencies similar to x-rays and damaging radiations during the clinical testing. The tests required by imaging techniques must be performed repeatedly over a long period of time, which can damage molecules in the human body. In light of these concerns, we suggest a tissue-equivalent phantom that can be employed in medical applications that imitates the dielectric properties found in human tissues. Clinical trials can use this tissue-equivalent phantom, which will lessen the need to sacrifice animals and the risk to humans.

Microwave technologies serve a crucial part in a variety of medical and industrial applications, including medical imaging, hyperthermia treatment, and non-invasive testing. However, accurate calibration and validation of microwave devices require the availability of tissue-equivalent phantoms that closely mimic the dielectric properties of biological tissues [7]. Current difficulties in the field include a lack of standardized, consistent, and realistic tissue phantoms designed specifically for microwave frequencies ranging from 500 MHz to 1 GHz. The current tissue-equivalent phantoms may not accurately replicate the dielectric properties of human tissues in the microwave frequency part within consideration. This limitation restricts the development and testing of microwave devices, compromising the dependability and accuracy of medical diagnostics, therapeutic treatments, and industrial applications. The development and characterization of an improved tissue-equivalent phantom for the specified microwave frequency range will address these issues, thereby contributing to the improvement of microwave technologies in medical and industrial environments. The purpose is to develop a standardized and reliable testing medium that closely mimics human tissues, ensuring the efficacy and safety of microwave-based devices in a variety of applications.

## 1.3 Objectives

The project's objectives are as follows:

- To investigate Tissue Equivalent Phantom materials for microwave applications (500 MHz – 1 GHz).
- To develop and characterize Tissue Equivalent Phantom materials for microwave applications (500 MHz – 1 GHz).

## 1.4 Scope of work

The scope of this research is to conduct a review of the literature regarding the various tissue-equivalent phantoms operating in the 500 MHz to 1 GHz frequency range. A literature review provides information in the form of a written report and seeks to gain a better understanding of the research and discussions that have already been conducted on a specific topic or field of study. As a result, completing a literature review assists us discover more about our pertinent issue.



The second scope is to develop a list of ingredients and recipes that closely resemble the dielectric properties found in human tissue. The phantom's relative permittivity and loss tangent can be changed by adjusting the recipe.

The third scope of this project is to analyze the conductivity and relative permittivity of muscle, fat, and skin in relationto frequency. The main consideration in replicating real tissue is the tissue-equivalent phantom's dielectric properties. The performance probe design of the Agilent 85070E Dielectric Probe Kit will be utilized to measure the dielectric properties.

Figure 1.1 shows the scope of the work which is divided into six parts. The first part is the type of phantoms: Liquid, semi-solid, and solid. The objective of the project is to develop a semi-solid based phantom that resembles real human tissue; hence the scope has been restricted to this area. Next, the type of tissues: skin, fat and muscle. This project will develop the type of tissues in the scope. The methods used to measure the dielectric properties are numerous and each is associated with a specific frequency, material, application, and other elements. The open-ended coaxial and transmission line method is the most effective for assessing the tissue's dielectric properties in comparison to the free space technique. There are numerous subranges within the electromagnetic spectrum, which covers the entire spectrum of electromagnetic radiation. X-rays and radio waves are used by the majority of biological devices, but this research is based on microwave frequency of 500 MHz to 1 GHz. The dielectric properties, which include permittivity, conductivity, and loss of tangent, will then be measured as part of this study.

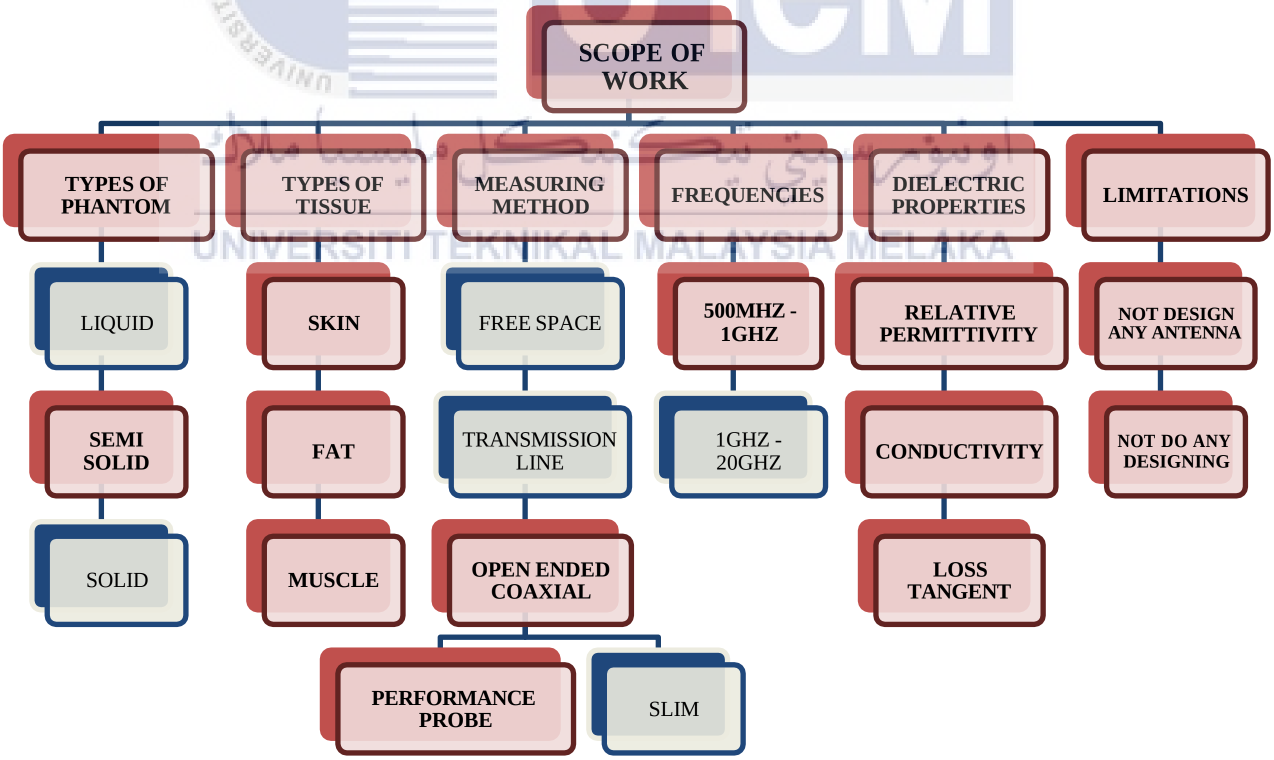



**Figure 1.1: Scope of work this research.**

## 1.5 Thesis structure

This thesis has been divided into five chapters: an introduction, a background study, a methodology, a result and discussion, a conclusion, and future work. The project's introduction was explained in Chapter 1. An outline of the project's preliminary research was given at the beginning of the project. All of the problems with the ventures were fixed after the context. The project's purpose is determined by the problem statement, and the scope of work is also assessed.

The background research for the project had been discussed in Chapter 2. Based on the project's title, a background study from recent journals has been completed, covering the different types of tissue-equivalent phantoms, the dielectric properties of biological tissues, applications for these phantoms, and measurement techniques. Background investigation was also done on the components and supplies needed for creating tissue-equivalent phantoms.

The flow of the project methodology was provided in Chapter 3. Perform a literature review on recent articles and a website that includes project-related issues like the different kinds of tissue phantoms, the characteristics of human tissues' dielectric properties (skin, muscle, and fat), the procedure and recipe for creating the tissue phantoms at the desired frequency, and the application used.



The project results were explained and briefly explored in Chapter 4 of this project proposal. The developed tissue-equivalent phantom's relative permittivity, conductivity, and loss tangent will be discussed.

Finally, Chapter 5 discussed the conclusions and recommendations for making a project more sustainable in the future.

# CHAPTER 2

# BACKGROUND STUDY



This chapter outlines the study's literature review, which was carried out in order to acquire as much information as possible for this research. All information will be properly cited and obtained from relevant papers, scholarly publications, books, and internet resources. This part will detail and discuss the phantom recipe, types of tissues, types of phantoms, frequency bands, transcutaneous energy transfer and existing papers on various forms of phantoms in terms of capacity, specification, qualities, and the benefits and limitations of all the elements used in this project.

## 2.1 Tissue structure in human anatomy

Tissue structure refers to the exact arrangement and composition of cells, extracellular matrix, and other molecular components that unite to produce the many tissues found in the human body. The human body is made up of billions of smaller structures of four main types: cells, tissues, organs, and systems. The purpose of this research is to investigate the anatomy of tissue structure for the microwave applications. As a result, some of the most frequent human body parts, such as the hands, legs, and chest, are made up of three types of tissues, mainly skin, fat, and muscle, which were predicted to streamline the numerous elements and physical properties of an anatomical model [8]. Understanding tissue structure is important for understanding the complexities of human anatomy and the interactions of multiple parts that sustain life and functionality.

### 2.1.1 Skin tissue oh human

The skin is the biggest organ in the body. It completely envelops the body. It acts as a barrier against heat, light, damage, and infection. The skin is a complex tissue made up of three layers: the epidermis, dermis, and hypodermis, each with its own structure and function. The skin is the body's first line of defense against diseases, UV rays, toxins, and mechanical harm. It also regulates the amount of water discharged into the atmosphere as well as body temperature [9]. It possesses inhomogeneous dielectric properties due to its highly inhomogeneous composition.



The epidermis is the skin's thin outermost layer. It is composed of three types of cells. The epidermis is the thinner layer of skin, but it protects you from the elements. The epidermis has five layers on its own. It also supports several cell types: keratinocytes formulate keratin, the major component of the epidermis. Langerhans cells keep foreign particles out of your skin. Squamous cells are the stratum corneum where the outermost layer that is constantly destroyed. Basal cells are located at the base of the epidermis, within the squamous cells. Melanocytes are responsible for the pigment in your skin known as melanin. Melanocytes can be found close to the base of the epidermis and generate melanin. This is essentially giving the skin its color. The stratum corneum, which defines the dielectric properties of the epidermis, is the most significant of the epidermis's numerous layers. The layer is made up of smooth, dead skin cells and dissipates every two weeks or so. Despite its thinness, which is typically approximately 20 µm, it contributes greatly to the dielectric properties of the skin [10]. The dermis is the middle layer of skin. This is the layer that contributes to wrinkles. The dermis is a complex structure that includes blood vessels, hair follicles, and oil glands. Collagen and elastin are two proteins that are essential for skin health because they provide support and suppleness. This layer provides flexibility and strength to the skin. Fibroblasts are the cells found in this layer because they produce collagen and elastin. This layer includes nerves that detect pain, touch, and temperature. The resistivities of subcutaneous tissue are lower relative to those of the upper layers. Despite its thinness, the stratum corneum is responsible for the majority of skin resistance, particularly in the low-frequency region below 10 kHz. According to research, the stratum corneum accounts for around 50% of total skin impedance at frequencies below 10 kHz but only about 10% at frequencies above 100 kHz [11-14]. The innermost layer of skin is the subcutaneous fat layer. It is made up of a collagen and fat cell structure. The loss of tissue in this layer is what causes your skin to sag and wrinkle. Sweat glands, fat, and loose connective tissue are all found in this stratum. The subcutis is in charge of retaining body heat and safeguarding crucial internal organs.

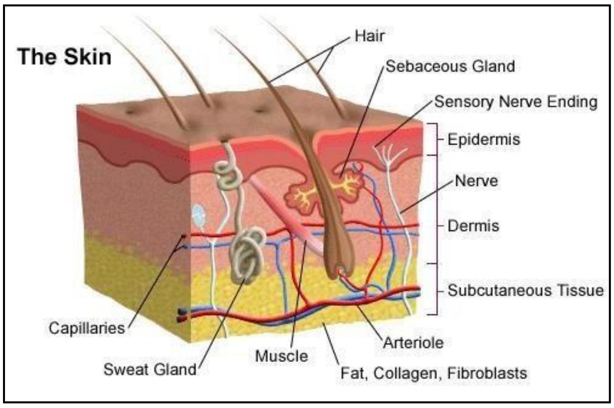



**Figure 2.1: The structure of human skin in cross-section.**

### 2.1.2 Fat tissue in human

Adipose tissue, often known as body fat, is a connective tissue that stretches throughout the body. It can be found beneath your skin (subcutaneous fat), between your internal organs (visceral fat), and even within the spaces of your bones (bone marrow adipose tissue). Body fat is most known for its ability to store and release energy, as well as provide insulation. Adipose tissue comprises nerve cells and blood arteries and communicates with various organs throughout your body over hormone signals. Water is a more effective conductor of electricity than fat tissue, despite the fact that fat tissue is a poor conductor of electricity. Thus, changes in the amount of body fat or water indicate changes in tissue resistance. Furthermore, adipose tissue has the lowest dielectric properties of any tissue, including skin and muscle. As a result, fat tissue has lately contributed to medical and communication applications, particularly fat intrabody communication [8] [15-16]. In addition, researchers have conducted considerable research on medicinal applications such as laser-tissue thermal interaction [17] and adipose tissue derived stem cell [18-19].

### 2.1.3 Muscle tissue of human

Muscle tissue is formed out of cells that have the potential to shorten or contract in order to move bodily components. The tissue is densely cellular and rich in blood vessels. Because the cells are long and slender, they are sometimes referred to as muscle fibers, and they are normally grouped in bundles or layers that are bordered by connective tissue. Actin and myosin are contractile proteins found in muscle. Muscle tissue can be classified into three types: skeletal muscle tissue, smooth muscle tissue, and cardiac muscle tissue. Recent publications on muscle tissue research have included applications such as cardiac muscle tissue engineering [20-21] and drug delivery system.

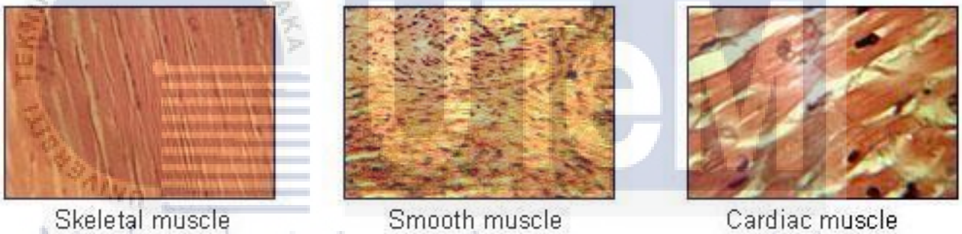



**Figure 2.2: The types of muscle tissue.**



Electrical conduction along the length of the fiber is substantially easier than conduction between fibers in the extracellular matrix because the extracellular matrix is less conductive than the cell. Muscle tissue possesses a common anisotropic electric property as a result. Even when charge transport path differences are addressed, longitudinal conductivity is substantially greater than transverse conductivity, especially in the low-frequency band. In other words, if the current frequency is high enough, the anisotropic features disappear (especially for muscle tissue, which occurs in the MHz frequency range). Large-scale structures become less important as charge transfer occurs over shorter distances at higher frequencies, and capacitive coupling across membranes becomes more important. As a result, muscle tissue exhibits medium conductivity to electricity.

## 2.2 Microwave applications

There are many applications in microwave such as Medical Implant Communication System (MICS), wireless hospital temperature, and Industrial, Scientific, and Medical (ISM) bands. Microwave technology provides an important role in providing wireless communication for Medical Implant Communication Systems (MICS). These systems provide bidirectional data interchange between implanted medical devices, such as pacemakers or neurostimulators, and external receivers or programmers. Microwaves, usually in the radiofrequency (RF) spectrum, enable a dependable and non-invasive method of communicating critical health data, device status, and programming instructions between the implant and the external healthcare infrastructure. Microwave sensors have uses in wireless hospital temperature monitoring systems. These microwave-frequency sensors may provide precise and real-time temperature data in a variety of medical settings, including patient rooms, laboratories, and storage areas. The wireless design of these sensors reduces the need for costly wiring, allowing for more flexible and convenient temperature monitoring. The ISM bands, which include frequencies such as 2.4 GHz and 5.8 GHz, are commonly used for wireless communication in a variety of healthcare applications. In medical environments, these bands allow the use of wireless technologies such as Wi-Fi and Bluetooth for transmitting data between medical devices, hospital equipment, and information systems.

## 2.3 Dielectric properties theory

The frequency changes in relative permittivity and electrical conductivity are appropriately taken into consideration. An attempt was made to offer facts that can be regarded typical for each material. The dielectric properties of aqueous solutions of amino acids, polypeptides, proteins, and ultimately cells are initially explained in order to develop a structure for understanding the properties of tissues. The most important elements used for replicating the dielectric properties of biological tissues are relative permittivity ($\varepsilon_r$), conductivity (σ), and loss tangent (tan δ). Because all of these elements are frequency dispersive, frequency is going to perform an essential role in producing tissue-equivalent phantoms.

### 2.3.1 Relative permittivity, $\varepsilon_r$

The dielectric constant, indicated by k, is a number that measures the capacity of an applied electric field to hold electric charges relative to a vacuum.



$$k = \frac{c}{c_o} \tag{2.1}$$

Where:

$c$ = The capacitance of a capacitor with dielectric material.

$c_o$ = The capacitance in a vacuum without dielectric material.

The relative complex permittivity ($\varepsilon_r \varepsilon_r$) in free space is defined as follows:

$$\varepsilon_r = \frac{\varepsilon}{\varepsilon_o} = \varepsilon' r - j\varepsilon'' r \tag{2.2}$$

Where:

$\varepsilon$ = The permittivity of substance.

$\varepsilon_o$ = The permittivity of vacuum or free space.

The dielectric permittivity of a substance, represented as, has a real and an imaginary part. The imaginary permittivity ($\varepsilon''_r$) and the angular frequency [$\omega = 2\pi f\omega$ = $2\pi$f] can be related as follows:

$$\varepsilon'' = \sigma/\omega \qquad (2.3)$$

$$\varepsilon''_r = \sigma/\omega\varepsilon_o \qquad (2.4)$$



### 2.3.2 Conductivity

The conductivity of a dielectric substance is its capacity to conduct electrical current and provides an illustration of the quantity of stored energy that the material loses as heat when exposed to an applied electric field. The complex permittivity, which consists of real and imaginary permittivity, is used to calculate the conductivity value. The conductivity was calculated using the formula that is shown below.

$$\sigma_r = \frac{\varepsilon''}{\varepsilon'_r}\omega\varepsilon_o \qquad (2.5)$$

Where,

$$\varepsilon_o = 8.85 \times 10^{12} \qquad (2.6)$$

### 2.3.3 Loss tangent

A material's dielectric loss tangent (tan δ) quantifies electrical power dissipation caused by numerous physical processes such as electrical conduction, dielectric relaxation, dielectric resonance, and non-linear processes. Furthermore, the delay between the electric field and the vectors of electric displacement might be connected to the cause of dielectric losses. The total dielectric loss is the sum of intrinsic and extrinsic losses. Intrinsic dielectric losses are losses in perfect crystals induced by the interaction of the phonon system with the alternating current electric field and are structural dependent. Figure 2.3 illustrates the relationship between human skin's relative permittivity and loss tangent. The graph shows that relative permittivity is inversely related to frequency.

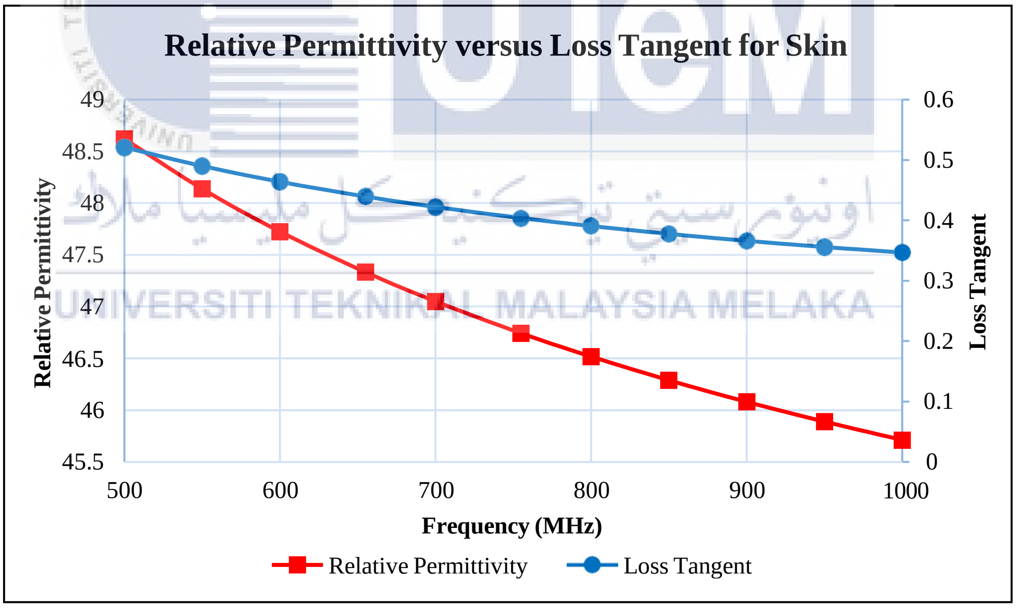



**Figure 2.3: A graph of relative permittivity against loss tangent for skin at frequencies range from 500MHz-1GHz [22].**

### 2.3.4 Summary of human tissue's dielectric properties

Table 2.2 shows the dielectric properties of human tissues (skin, fat, and muscle) throughout a frequency range of 500 MHz to 1 GHz. All data were acquired from the Italian National Research Council website [22].

**Table 2.1: The range of dielectric properties of human tissue between 500 MHz to 1 GHz [22].**

| Tissue | Relative Permittivity | Conductivity (S/m) | Loss Tangent |
|---|---|---|---|
| **Skin (Wet)** | 48.621– 45.711 | 0.70444 – 0.88181 | 0.52087 – 0.34676 |
| **Skin (Dry)** | 44.915 – 40.936 | 0.7284 – 0.89977 | 0.58303 – 0.3951 |
| **Fat** | 5.5444 – 5.447 | 0.042793 – 0.053502 | 0.27748 – 0.17656 |
| **Muscle** | 56.445 – 54.811 | 0.82245 – 0.97819 | 0.52383 – 0.3208 |

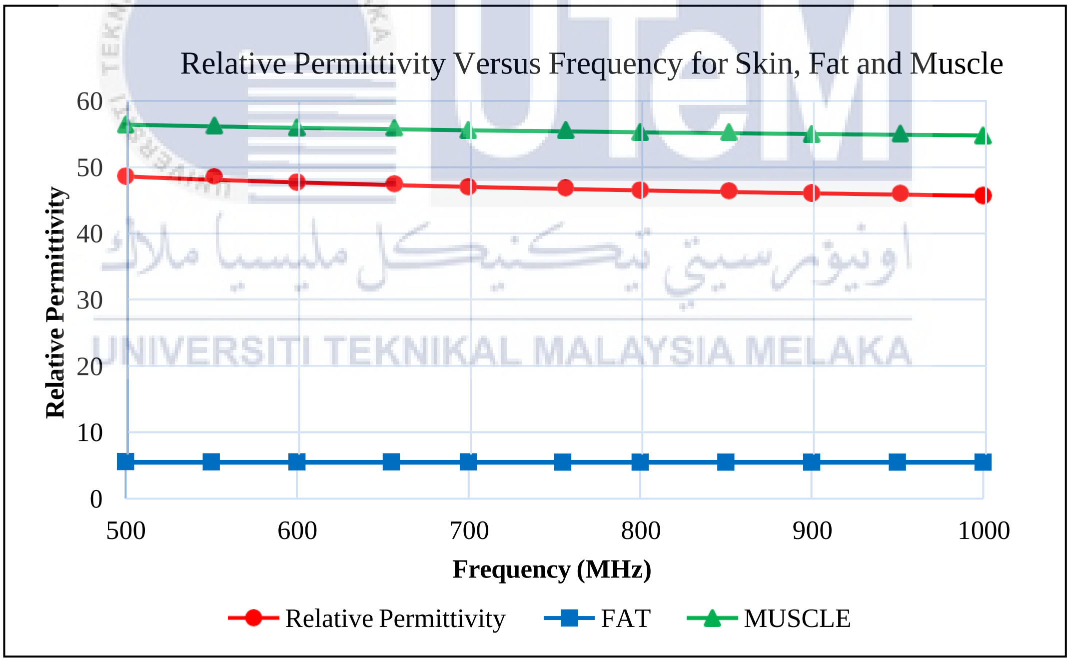





**Figure 2.4: The relative permittivity of skin, fat and muscle against frequency (500 MHz to 1 GHz).**

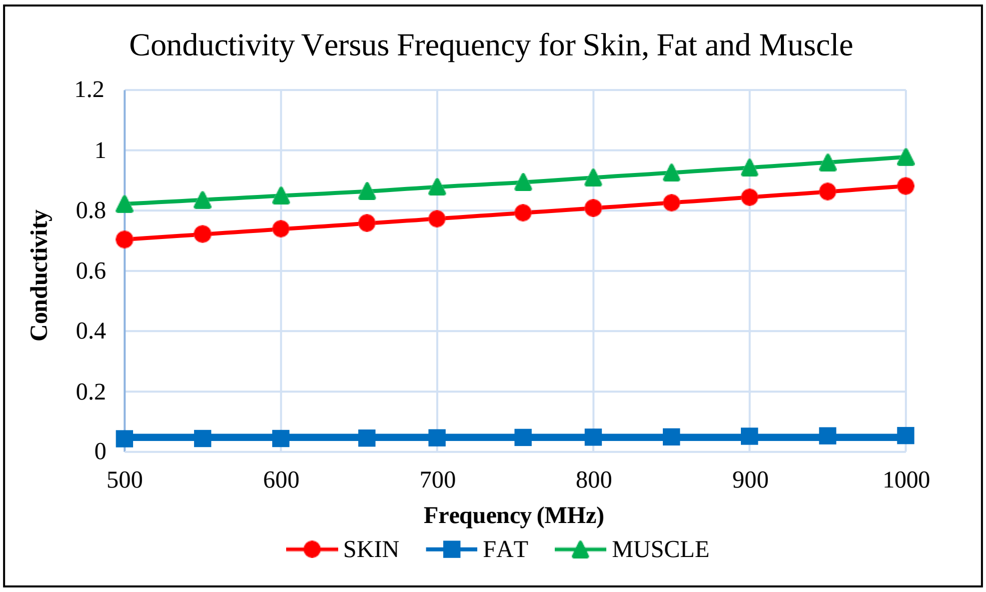



**Figure 2.5: The conductivity of skin, fat and muscle against frequency (500 MHz to 1 GHz).**

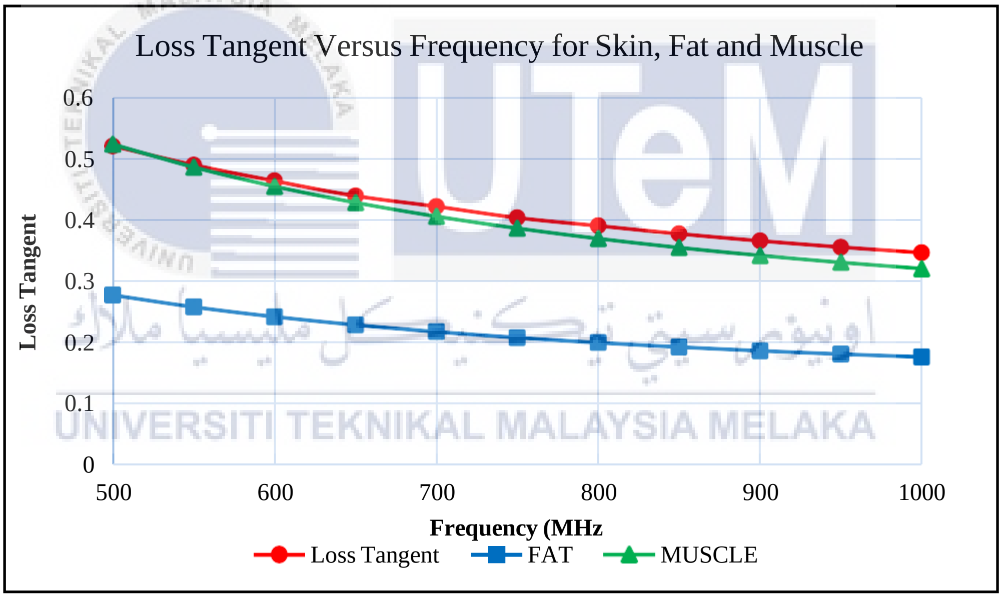





**Figure 2.6: The loss tangent of skin, fat and muscle against frequency (500 MHz to 1 GHz).**

## 2.4 Dielectric properties of tissue and materials

The dielectric properties of any material indicate information about the substance's suitability for potential applications. The dielectric properties of each material and tissue employed during the laboratory research were measured in this thesis work to demonstrate that these values are similar to the real human tissue values. It is also essential for comprehending the dielectric materials' properties, particularly permittivity and loss tangent at laboring conditions. This was covered in the previous section. There are six measuring approaches for a material's dielectric constant and loss tangent, according to Keysight Technologies application note [4]. The techniques used consist of coaxial probe, transmission line, free-space resonant cavity, parallel plate, and inductance measurement. Different parameters, such as frequency range, accuracy, material from (liquid, solid, or semi-solid), and measurement convenience, must be considered when selecting the most appropriate measurement technique. The coaxial probe measurement technique was chosen after careful consideration since it is an ideal approach for measuring homogeneous and semi-solid materials.



## 2.5 Tissue equivalent phantoms

According to background research and a survey of the literature, there are 3 main types of tissue-mimicking phantoms: liquid, solid, and semi-solid. The sort of tissue or body components we want to construct should determine the state of matter for the tissue-equivalent phantom. For example, if a breast phantom is developed, a semi-solid state would be ideal since it most closely resembles the anatomical and biological features of a real human breast. For instance, if we were to develop a hand phantom, it would need to be layered and constructed similarly towards how human skin is.[2]

This type of phantom is called a "tissue-equivalent phantom" since it is similar to human skin in structure. When creating a tissue-equivalent phantom, other parameters like the frequency and dielectric properties of human tissue must be taken into account. The conductivity and relative permittivity of human tissue are the most crucial factors in creating a tissue-equivalent phantom.

Despite the fact that numerous animals are murdered every year in laboratories around the world, the majority of nations have gravely deficient laws and regulations in place to safeguard animals from pain and suffering or to stop them from being used when a non-animal strategy is easily available. Mice, rats, birds, fish, reptiles, and amphibians are the most often utilized experimental species in the United States, although they are specifically exempt from even the most basic safeguards provided by the federal Animal Welfare Act (AWA). Excluding rats, mice, birds, reptiles, amphibians, and agricultural animals used in research on agriculture, there are an estimated 100 million mice and rats, as well as about 1 million animals kept in captivity in labs or used for experiments [3].



In addition to a transmission-based sensing technique for non-invasive tumor detection, the researcher created a heterogeneous breast phantom with inclusion models for skin, fat, muscle, and spherical tumors. The skin phantom's dielectric properties have been improved by the researcher. A Keysight Technologies open-ended coaxial slim probe is used to measure the breast phantom's dielectric properties [4].

The skin is the largest organ in the body, both in terms of weight and surface area, and it serves as a barrier between the body's internal environment and the outside world. It serves as a means of communication with the outside world, protects the body from water loss, guards the body from ultraviolet radiation using specialized pigment cells called melanocytes. Adults have a 2 square meters (22 square foot) surface area and a 5 kilograms weight. Skin can be as thin as 0.5mm on the eyelids or as thick as 4.0mm on the heels of your feet. Our body is covered in a connective tissue called adipose tissue, also referred to as body fat. Visceral fat between your internal organs, subcutaneous fat beneath your skin, and even bone's internal cavities all contain it (bone marrow adipose tissue). The main functions of body fat are energy storage, energy release, and insulation. Adipose tissue connects with various organs throughout your body through hormone signals and contains nerve cells and blood arteries. The 12th and 13th ribs are where the fat thickness in both species is assessed. A point three-fourths of the length of the ribeye cross-section from the chine bone side is chosen for the measurement, which is taken perpendicular to the fat cover [5]. Muscle tissue is made up of cells with the unique capacity to constrict or shorten to cause movement of the bodily components. The tissue is densely packed with cells and has many blood channels. Because of their length and thinness, the cells are sometimes referred to as muscle fibers. They are typically grouped in bundles or layers and are encircled by connective tissue. Muscle tissue contains the contractile proteins myosin and actin. Skeletal muscle tissue, smooth muscle tissue, and cardiac muscle tissue are the three types of muscle tissue [5].



Microwaves are non-ionizing electromagnetic radiation that transmits electrical and magnetic energy at different frequencies. They are frequently used in a wide range of industries, including food, telecommunications, meteorology, and medical. Microwave applications in medicine are a relatively recent industry that is gaining popularity, with a significant trend in healthcare research and development. Microwaves were first used in medicine in the 1980s to treat cancer using ablation therapy; their applications have since extended. Significant progress has been achieved in the transformation of microwave data for imaging and sensing applications in healthcare. Microwave energy is a type of electromagnetic radiation with a frequency range of 300 MHz to 300 GHz. The commonest frequency occurs around 2.45 GHz, which fits within the industrial, scientific, and medical radio frequencies. In recent years, microwave energy has been used in the healthcare industry for a variety of applications, especially at frequencies other than 2.45 GHz [6]. The interaction of microwaves with polar molecules within substances provides a foundation for a variety of advancements. Microwave energy is a type of non-ionizing radiation that does not change the molecular structure of biological tissue and has numerous biomedical applications. Microwave energy has a promising future in the healthcare system. There are thermal and nonthermal interactions with microwave energy. Mumtaz et al. summarized the biological consequences of microwave energy, showing that continuous microwave energy emission causes electrons and ions to oscillate in a changing electric field, increasing the temperature in biological tissue. However, there may be errors and limitations regarding evaluating tissue dielectric properties and utilizing microwave technologies in the healthcare industry. The sensing depth for detecting dielectric properties can vary significantly and addressing this can help medical technology development. Although microwave methods for imaging have significant benefits over conventional imaging technologies, there are several limitations, such as phase distortion within biological tissues, high EM wave attenuation, and tissue penetration depth [7].

Tissue-equivalent phantoms are classified into three types: solid, liquid, and semi-solid, which will be discussed further. Table 2.3 provides a summary of recent research on tissue-equivalent phantoms, which is sorted by most relevant to this topic.

**Table 2.2: Recent studies on tissue equivalent phantoms for diverse applications.**

| Year | Tissue | Type of phantom/Frequency | Findings |
|---|---|---|---|
| 2015 [2] | Head, breast, limb, and torso | Liquid, semi-solid, and solid (Various frequency band) | This article discusses a review of the developed phantoms. First, the numerous uses of artificial human phantoms are discussed in order to emphasize the importance of the phantoms. The advantages and downsides of various in qualitative analysis, different sorts of materials are contrasted. Furthermore, the researcher studied at the phantoms for specific body parts based on their features and applications. |
| 2019 [23] | Head and Brain | Solid (1 kHz–1 MHz) | In this research, solid tissue-mimicking materials were developed. The tissue-mimicking materials' AC conductivity profiles are intended to cover the biological conductivity range, as defined by blood (high conductivity) and fat (low conductivity). The conductivity of any tissue, such as blood or fat, can be mimicked by the tissue-equivalent phantom. Isopropanol, which increases |

| | | | |
|---|---|---|---|
| | | | the conductivity of a mixture, is now able to be employed to mimic extremely highly conductive tissues such as urine. |
| 2021<br><br>[24] | Fat | Semi-solid<br><br>(100 MHz – 2 GHz) | The research study investigated into agar and kappa carrageenan formulations for developing emulsion gels that might be employed as tissue simulating phantoms. The results showed that agar had a significant capacity for oil droplet stabilization, resulting in gels with smaller and more uniform oil droplets. Surfactants were used to boost the oil content while lowering the gel strength and stiffness. The permittivity and conductivity of the gels were reduced by increasing the oil content, specifically in the agar gels, resulting in materials with dielectric properties similar to those of low-water-content tissues. These findings show that polysaccharides can be used to create a variety of tissue-like phantoms with a wide range of mechanical and dielectric properties. For the development of fat phantoms, agar gels with a high content of oil are |

| | | | |
|---|---|---|---|
| | | | desirable. When emulsion gels are utilized, however, the phantom's stability is only temporary. |
| 2017 [25] | Muscle | Semi – solid (13.56 MHz – 2450 MHz) | Dosimetry studies implementing a wide variety of RF frequencies are required to develop radiofrequency (RF) heating methods for treating tumors at varied locations and depths in patients. Eleven formulas for simulating muscle at frequencies ranging from 13.56 to 2,450 MHz are presented. To be helpful for tissue-heating applications, the phantom model's dielectric properties must closely resemble those of tissue over the temperature range of interest. Due to the limitations on the amount of aluminium powder required to obtain the proper dielectric properties without significantly increasing heat conductivity, no attempt was made to analyze frequencies lower than 13.56 MHz. Higher frequencies over 2,450 MHz were not investigated because their medical usage is unlikely due to limits on limited penetration depth. |

| | | | |
|---|---|---|---|
| 1989 [26] | Muscle | Semi-solid (10-50 MHz) | These gelatine, water, and sodium chloride phantoms have been developed for simple and low-cost simulation of most human tissues at temperatures ranging from 15 to 50 degrees Celsius and frequencies ranging from 10 to 50 MHz. The changes in relative permittivity and conductivity as a function of temperature between 15- and 50-degrees C. |
| 2022 [27] | Breast | Semi-solid (50 MHz to 20 GHz) | To develop a tissue-mimicking phantoms that approximate the temperature-dependent dielectric properties of breast tissue, allowing for the development of an innovative MWI system that uses tissue's temperature-dependent permittivity as a natural contrast agent. A temperature increase causes a different change in the complex permittivity in tumor tissue than in surrounding tissue because tumor tissue has a higher water content. The characterization utilized measurements with an open-ended coaxial probe and a network analyzer. |

| | | | |
|---|---|---|---|
| 2008 [28] | Skin, fat, and muscle | Semi-solid (600-1000 kHz) | Analysis of biological tissue around an air-core transcutaneous transformer for an artificial heart's current density and specific absorption rate (SAR). The transmission line modelling approach is used to investigate the electromagnetic field in biological tissue. The layers of biological tissue that maximized current density differed according to frequency; muscle in the low frequency and skin in the high frequency. The frequency 600-1000 kHz is close to the barrier. |
| 1992 [29] | Muscle | 10-100 MHz (Semi-solid) | Glycine is used to obtain the large permittivity of muscle at frequencies below 100 MHz. The lack of suspended solids simplifies preparation, and ensures the dielectric properties are homogeneous, stable, and reproducible. The solutions are transparent, facilitating placement of probes for measuring temperature or electric field. The optical clarity of the phantom mixture may also be desirable in a quick assessment of RF applicators. |

| | | | |
|---|---|---|---|
| 1982 [30] | Non tumour | 0.1 and 100 MHz | Dielectric permittivity and conductivity measurements are reported from various soft excised mammalian non-tumor tissues, at frequencies between 0.1 and 100 MHz. The data over this wide frequency range can be well represented by a Cole-Cole equation for either the complex conductivity or complex permittivity. A summary of fitted parameters for the tissue data is presented. The data are compared to older data that are still frequently quoted. |
| 2019 [31]] | Forearm<br>Fat<br>Muscle<br>Blood tissue | 1 kHz – 2 MHz<br>(Semi-solid) | This study developed a human forearm phantom to analyze the dielectric properties of fat, muscle, and blood tissue domains for bioimpedance analysis. The tissue simulants were identified based on conductivity and permittivity values within the β dispersion frequency range. A mixture of 80% propylene glycol and 20% saline replicated blood properties, while agar and saline mimicked fat and muscle properties. |

### 2.5.1 Solid phantoms

Solid phantoms are also known as dry phantoms because they do not contain any water-based elements. The most significant advantage of these phantoms is that they do not dehydrate. Primary materials for solid phantoms include ceramic powders, graphite, silicon rubber, carbon fiber, urethane rubber, and carbon nanotubes. Nevertheless, the fabrication procedure is more difficult and expensive because these phantoms develop at high pressure and temperature conditions. Moreover, they cannot be cut or reshaped, in contrast to semi-solid phantoms. Figure 2.7 imagines a solid phantom, which is a multilayer stylized head phantom that does not let the probe to penetrate during the measuring procedure, rendering it unsuitable for use in implantable devices [24].

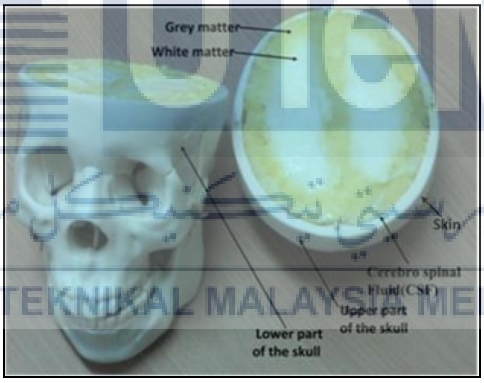



**Figure 2.7: Multilayered stylized solid head phantom.**



### 2.5.2 Liquid phantoms

In their early beginnings, most phantoms were liquid-based. Artificial tissue-equivalent (ATE) liquid-based phantoms are primarily used for tissues with high dielectric permittivity and loss, such as muscle, brain, and cancerous cells. Water is the primary element in the phantom composition that mimics the strong electrical characteristics. Low permittivity tissues, such as fat, bone, and skin, can be produced by altering the amount of water in the tissues, resulting in a lower water content. One of the primary benefits of liquid phantoms is their ease of production. On the other hand, water evaporation from the phantom products will lead to changes in the electrical properties. Figure 2.8 shows a thyroid liquid phantom that requires a container to be stored, and mould growth in the container effects the phantom's electrical properties. Because of these properties, liquid phantoms are inappropriate for long-term preservation.

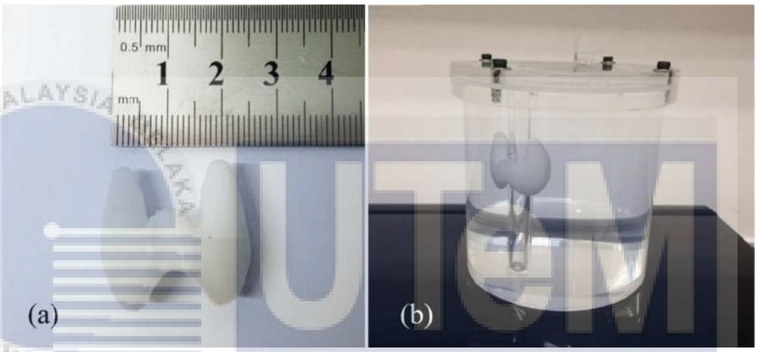



**Figure 2.8: Thyroid liquid phantom in a container for computed tomography (CT).**



### 2.5.3 Semi-solid phantoms

Semi-solid ATE phantoms can be used to simulate both high and low permittivity tissues by utilizing materials such as gelatin, agar, dough, or starch. Using diverse frequency dispersive tissues, they can replicate tissues for narrowband and broadband applications. Figure 2.9 shows a breast phantom with a tumor implanted for spectroscopic measurements. It is apparent that the breast phantoms are flexible and do not require a container after they have been produced. These phantoms are solid and can be moulded following the phantom moulding process by using flexible and conformable dough or starch. Because particle dispersion does not occur across neighboring levels of the phantom, it is easier to create multilayered heterogeneous phantoms that realistically mimic the human body.

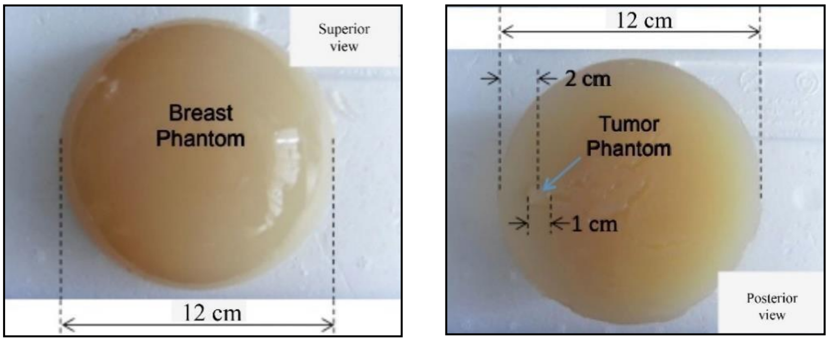



**Figure 2.9: Breast semi solid phantom with tumor inserted.**

## 2.6 Phantom recipe and materials

From diverse perspectives, the materials used to construct the tissue-equivalent phantom can be categorized into different categories. Depending on the dielectric characteristics, they can be tissuing phantom substances with low or high-water content. Each material used for making a tissue phantom has a specific dielectric constant value. The dielectric constant value is useful for researchers in determining whether the material is appropriate for the type of phantom. Although this classification assists in determining whether a particular tissue-equivalent phantom type is suitable for replicating a specific tissue, it does not explain why one type of tissue phantom is preferable to another. Consequently, Table 2.4 provides a detailed explanation of the materials that are frequently employed to make phantoms, together with information on their characteristics and functions. To analyze the pros and cons of each form, the phantom materials are split into three categories depending on their physical appearance. The purpose of the research is to develop a semi-solid tissue-equivalent phantom that is flexible, malleable, and reshapable. To achieve each of these tissue qualities, multiple iterations of material compositions must be researched.

**Table 2.3: Common materials used for developing phantoms and their functions.**

| Ingredients | Characteristic | Functions |
|---|---|---|
| Deionized water (DI) | Deionized water serves as a base material or solvent for dissolving and mixing other components. | Deionized water can be used to create tissue-mimicking solutions by adding specific materials to achieve desired tissue properties such as density, acoustic properties, or electromagnetic properties. Using deionized water ensures consistency and reproducibility in the phantom's properties and performance. |
| Sodium Chloride (NaCl) | Salt that has crystallized. | By adjusting the concentration of sodium chloride, the conductivity of the phantom can be tuned to mimic specific biological tissues. Increase the value of imaginary part of $\varepsilon_r$ and $\sigma_r$ and vice versa for the real part of $\varepsilon_r$. |
| Gelatin and agar | Agar and gelatin are both gelatinous solids, with agar being a yellowish- | As a gelling agent to maintain the shape of the tissue-equivalent phantom while achieving the dielectric properties. |

| | | |
|---|---|---|
| | white powder and gelatin being colorless. | |
| Oil | A hydrophobic viscous liquid. | To generate low-water-content tissue phantom materials and to create heterogeneous structures within the phantom. |
| Polyvinylpyrrolidone (PVP40) | average molecular weight to control permittivity. | PVP40 facilitates the homogeneous mixing of various components in the phantom material, ensuring uniformity and consistency in the phantom's properties. Ensure consistency and reproducibility. |



After identifying the most often used materials for generating the tissue-equivalent phantom, the following step is to determine the most effectively recipe based on the ingredients list. The process involves the mixing of materials to obtain the desired structure, dielectric characteristics, physical texture, and other requirements. Little adjustments in the recipe can drastically alter the dielectric properties of tissue-equivalent phantoms. The most crucial parameter of the result is the phantom's dielectric properties. As a result, it is critical to select the suitable ingredients in order to get the desired result. A sufficient amount of any kind of element is essential during the fabrication process. As a result, changing the amount of each an element will cause the dielectric properties to change. As a result, sampling will be the most efficient method of producing our desired tissue phantom with almost comparable actual human tissue dielectric properties.

# CHAPTER 3

# METHODOLOGY



The entire procedure of developing and characterizing tissue equivalent phantom materials for microwave applications (500 MHz – 1 GHz) will be discussed in this chapter. This chapter provides a brief summary of the research technique, including the flowchart, materials and ingredients, production of the tissue-equivalent phantom, calibration process, and measurement of the tissue-equivalent phantom's dielectric properties. Furthermore, the phantom recipe has been established through literature research, and the necessary materials and ingredients for fabrication have been developed.

## 3.1 Flowchart of the project

Project planning is definitely necessary for accomplishing a project properly. A proper plan consists of a workflow that must be completed before to, during, and after the completion of the project. It establishes a point of view and a benchmark for the next stage of the project's completion. Figure 3.1 represents the project's flowchart, which includes numerous steps. The following is an exhaustive overview of the research methodology:

i. Literature review

Perform a literature review from recently published papers and a website based on project-related topics such as tissue phantom types, dielectric properties of human tissues (skin, muscle, and fat), the method and recipe to produce tissue phantoms at the desired frequency, and the application used, which is microwave applications.

ii. Choose and prepare the material and ingredients

The components for the phantom recipe will be finalized and compared based on the information acquired through the literature reviews in order to determine the ideal phantom recipe to replicate the most realistic dielectric properties for each type of tissue layer. During this process, the characteristics of each ingredient must be researched in order to develop a stable and good shelf-life tissue phantom over a long period of time without a significant change in electrical and physical properties, allowing multiple tests and measurements to be performed according to various applications. The materials and ingredients will be supplied.

iii. Development of tissue equivalent phantom (skin, fat and muscle)

Once the most effective phantom recipe has been discovered, the following step is to produce each layer of tissue phantom. During this stage, several sorts of phantoms will be produced simply by modifying the amount of ingredients in the formula.

iv. Perform using performance probe

Upon completing successfully fabricating the tissue phantoms, the following step is to calibrate the open-ended coaxial probe (Agilent 85070E Dielectric probe kit), which is used to measure the dielectric properties of the developed tissue phantom. The coaxial probe conduct is ideal for liquids and semi-solid (powder) materials. The procedure is basic, convenient, nondestructive, and only requires one measurement. The performance probe will be used for calibration instead of the slim probe because it was not included in this probe package. The performance probe can also be used to measure semi-solid materials, and the method of measurement is simple.



v. Phantom measurement

A typical measuring system contains an Agilent N5242A Network Analyzer and a performance probe. The characteristics of dielectric properties such as conductivity and relative permittivity will be proved during the measurement by comparing them to the dielectric properties of human tissues. The derived tissue phantom samples were maintained in a chemical refrigerator to prevent mould formation and to monitor the changes in the dielectric properties over time.

vi. Data collection and analysis

The generated tissue phantom's conductivity and relative permittivity will be measured and analyzed by comparing its dielectric properties to those of human tissues [22].

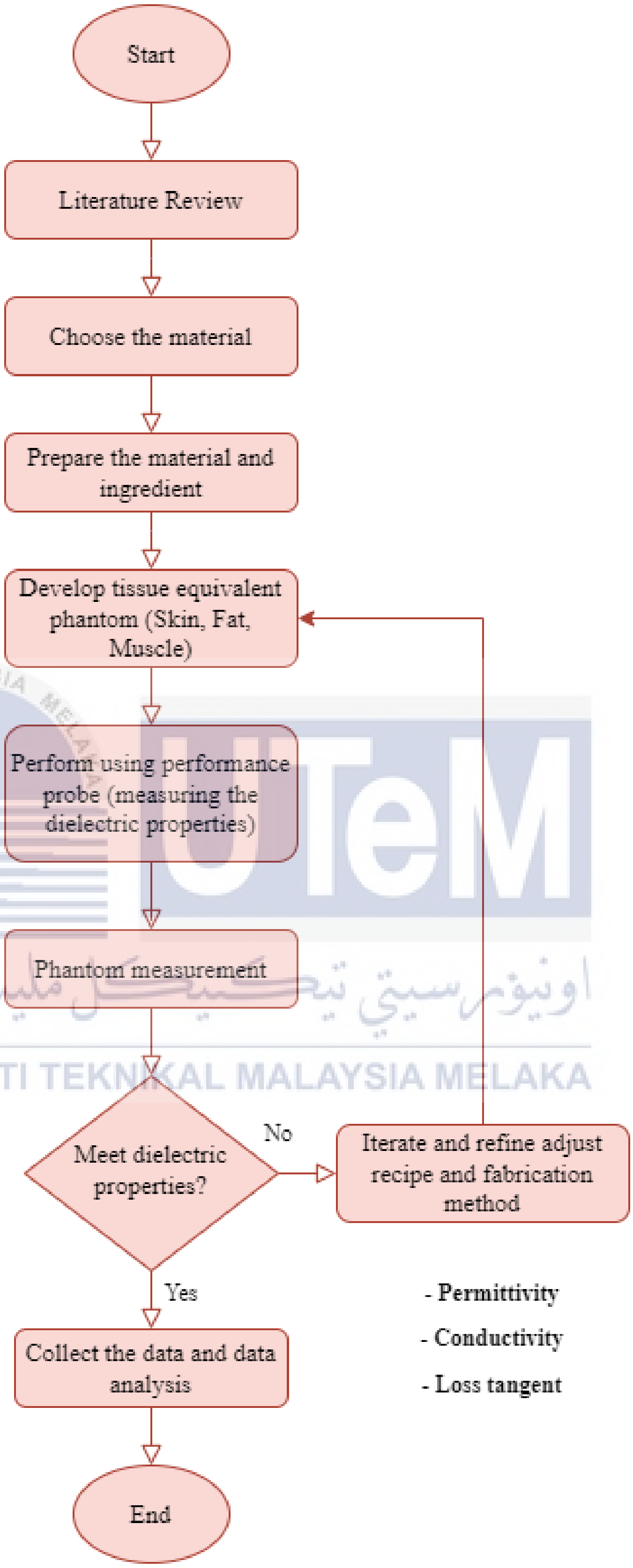





**Figure 3.1: The flowchart of the project.**

## 3.2 Ingredients and material

The most effective recipe for skin, fat, and muscle was finalized based on the substantial literature review from the previous chapter. The recipe was chosen based on crucial characteristics such as the dielectric properties of the materials employed, the shelf life of the phantom, physical properties, chemical content, and others. Table 3.1 to Table 3.3 indicate the ingredient ratios based on different samples for the fabrication of skin, fat, and muscle phantoms.

Purchasing the materials and ingredients required to develop the phantom took months because most of the essential ingredients were not available in Malaysia. As a result, some of the ingredients had to be obtained worldwide, which resulted in a higher price. Aside from that, some of the materials were very simple to obtain through the web platform because there was no requirement for travel through the supplier to obtain the things. The vast majority of the ingredients were food grade and could be obtained by anyone without limitation. However, purchasing some of the materials, such as Polyethylene powder (PEP) and N-propanol, was difficult because these items require seller approval and cannot be purchased by the general public without a stated use for the item purchased. Before the buyer may acquire the ingredients, the supplier will demand certain details such as the name of the company, application of the item, description of use, density, and others. The cost of the imported ingredients was prohibitively expensive due to the shipping charges, which could not be avoided because the supplier in Malaysia had no inventory of such things. Figure 3.2 shows some of the ingredients required for the development of skin, fat, and muscle tissue phantoms, which include agar powder, sodium benzoate, glycerin, and gelatin.

**Figure 3.2: The ingredients required for the development of tissue phantoms.**

**Table 3.1: The recipe for the proposed skin phantom.**

| **Ingredients (g)** | **Sample 1** | **Sample 2** | **Sample 3** |
|---|---|---|---|
| Deionized water (DI) | 50 | 50 | 80 |
| Glycerin | 19.23 | 19.27 | - |
| Maltodextrin | 12.14 | 12.14 | - |
| Gelatin | 10.93 | 25 | 25 |
| Sodium Benzoate | 0.5 | 0.5 | - |
| Salt (NaCl) | 1.04 | 1.04 | 0.45 |
| Xanthan Gum | - | 1.2 | 0.67 |
| PEP | - | 0.52 | - |



**Table 3.2: The recipe for the proposed fat phantom.**

| **Ingredients (g)** | **Sample 1** | **Sample 2** | **Sample 3** |
|---|---|---|---|
| Deionized water (DI) | 40 | 40 | 40 |
| Paraffin oil | 10 | 10 | 6 |
| Glycerin | - | 20 | 20 |
| Gelatin | 15.08 | - | 20.1 |
| N-Propanol | 4.15 | - | 4.15 |
| Salt (NaCl) | - | 0.6 | 0.6 |
| PEP | - | - | 0.47 |
| Agar | 1.4 | 1.4 | - |

**Table 3.3: The recipe for the proposed muscle phantom.**

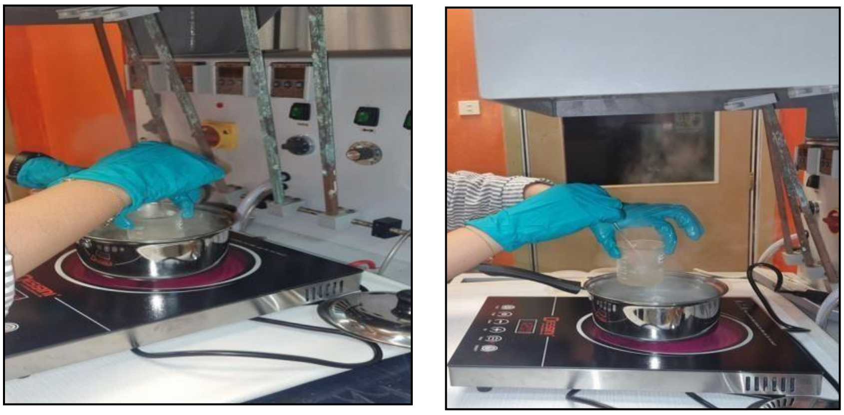
| Ingredients (g) | Sample 1 | Sample 2 | Sample 3 |
|---|---|---|---|
| Deionized water (DI) | 50 | 50 | 60 |
| PEP | 1.1 | - | - |
| Xanthan Gum | 0.66 | - | - |
| Carrageenan Gum | - | 1.25 | 1.25 |
| Agar | 0.8 | 1.55 | 1.55 |
| Guar Gum | 0.2 | - | 0.2 |
| Gelatin | 12.10 | 12.10 | 12.10 |

## 3.3 Process of development

The elements that were used for the phantom were measured using a Mettler Toledo analytical balance, which has a high level of precision up to 0.01 mg. Precise measurement of the ingredients is important for the development of phantom since small variations in the materials' mass might have an impact on their dielectric properties. The phantom was built in a well-ventilated laboratory, and the materials were kept in a chemical storage facility for precautionary purposes.




(a) Direct heating process.



(b) Double boiling process.

**Figure 3.3: The process of the development of tissue phantom using (a) Direct heating method (b) Double boiling method.**

### 3.3.1 The development process of skin phantom

The first step in developing skin phantom is to prepare all of the ingredients according to the recipe and measure the correct amount using an analytical balance to assure accuracy. Changes in an element quantity can affect the phantom's dielectric properties. Before beginning the producing process, the gelatin was presoaked for a few minutes in a tiny amount of deionized water to prevent particle clumping. The phantom's shape is maintained and its gelling agent function acts on by the gelatin.



The gelatin was then double-boiled in a beaker with an induction cooker and gently stirred with a glass rod until dissolved and transparent. After the gelatin turns transparent, foam will form on the top layer of the solution. The foam was removed using a stainless-steel spoon. Foam removal is essential for preventing the formation of air bubbles in the top layer of phantom. After removing the foam, the gelatin was double boiled with maltodextrin, a polysaccharide that thickening its texture and increases its volume and shelf-life. At the same time, glycerin was added to the molten gelatin in order to keep the moisture and texture of the phantom, followed by the remaining deionized water, which contributed to the phantom's relative permittivity. After carefully mixing the ingredients, the induction was turned off to stop the boiling process, and salt (NaCl) was added in order to improve conductivity and complex permittivity. Sodium Benzoate was added to the mixture as a preservative to prevent moulds. The mixture is gently mixed until all of the ingredients are well incorporated, and then cooled in a cold-water bath while stirring continually to allow the liquid to thicken. The skin phantasm is slowly put into a container and refrigerated to maintain moisture and prevent fungus growth. Three samples have been produced with new ingredients, including agar, xanthan gum, and polyethylene powder, for measuring changes in dielectric properties.

### 3.3.2 The development process of fat phantom

The development of the fat phantom is a challenge in this project since we need to achieve low relative permittivity, which means using less deionized water. The paraffin oil states to a low relative permittivity phantom. The ingredients and materials for the phantom were produced according to the recipe provided in Table 3.2 and measured with the Mettler Toledo analytical balance. Presoaking the gelatin and twice boiling it until it turns translucent is the same process used for producing a fat phantom as it is for a skin phantom. To prevent air bubbles from forming, the foam on top of the gelatin was removed. The oil solution was double-boiled in the same the pan as the molten gelatin. The mixture was constantly stirred until the oil and gelatin were well blended, and little oil drops of about 2 mm were seen on the top surface of the solution. Lastly, glycerin, a natural emulsifier, was added to the recipe to help the oil and melted glycerin stay together better and keep onto the phantom's moisture. N-propanol was added to the mixture and operates as a solvent, leading to a homogenous mixture. The mixture was slowly mixed until all of the ingredients were fully integrated before being poured into a circular container and allowed to cool at room temperature. After the phantom had totally cooled, it was kept in the refrigerator to preserve it.

### 3.3.3 The development process of muscle phantom

According to the previous development method of the skin and fat phantom, all of the elements were precisely measured before to making. Initially, the agar, salt, and Deionized Water (DI) were added together and heated in a pot made of stainless steel. The mixture was then gently stirred in order for the agar to dissolve completely. The salt increases the phantom's conductivity, while the deionized water adds to the high relative permittivity value of the muscle tissue. On the other hand, agar leads to the regulation of dielectric properties. After the agar had completely dissolved, the rest of the ingredients were continually added to the mixture with a strainer in little amounts. Finally, PEP was added to the dough-like mixture to reduce permittivity, and it was carefully mixed to avoid mixing in air, which would drastically influence the dielectric value. After the phantom had completely cooled at room temperature, it was stored in the refrigerator and placed in a container for the measuring process.

### 3.4 Process of measurement

Once the tissue phantom had cooled following the fabrication process, it was placed in the chemical refrigerator to prevent drying out and mould growth. Preserving the phantom is an essential element of the procedure because keeping it at room temperature can change the dielectric characteristics, and the dielectric needs to be measured a few times in a short period of time to analyze the dielectric properties. Measuring the phantom's dielectric properties was simple because no special apparatus or receptacles were required, and tests were non-destructive. Furthermore, it is appropriate for measuring semi-solid materials, such as the generated tissue phantom. The Agilent Technologies 85070E dielectric probe kit, if connected to an Agilent Technologies N5242A network analyzer, can measure from 500 MHz to 50 GHz and show the results up to 500 MHz.



**Figure 3.4: The Agilent Technologies dielectric probe and Vector Network Analyzer.**

The network analyzer detects the materials' response to microwave energy when the probe sends a signal into the Material Under Test (MUT). The sample measurement data are available in several formats, including ε′r, ε″r, loss tangent, and Cole-Cole. Due to a lack of slim probes in the laboratory, an open-ended coaxial probe was used along with a performance probe. This probe has a wide range and is suited for semi-solid samples [32-33]. Before measuring the dielectric properties of the phantom sample, performance calibration is required to ensure that the outcomes obtained are reliable and accurate for the analysis procedure. As a result, the calibration procedure was carried out by configuring the calibration, with the type of calibration set to air, short, and water, and the probe type set to performance. The frequency range was then set to 500 MHz to 1 GHz, and the calibration option was selected. The performance probe's lens was cleaned before pressing 'OK' to leave it in the open air. The shorting block was attached to the probe, and the option 'OK' was selected. The shorting block was removed, and a cup of water was placed into the probe and click 'OK'. Remove the cup and wipe the lens before measuring the sample. In order to ensure similar dielectric measurements, the sample was tested many times on the phantom's surface using the performance probe. The graph showed the values of the phantom's real and complex relative permittivity based on the frequency range. The measurement data were plotted on a graph for statistical analysis.

# CHAPTER 4

# RESULTS AND DISCUSSION



The result and analysis of the tissue phantom generated over the 500 MHz is discussed in this chapter. To generate a sample that matches actual human tissue dielectric properties, tissue-equivalent phantom samples were developed for each type of tissue, which is skin, fat, and muscle. The dielectric properties of each sample will be analyzed and compared with real human tissue data obtained from the Italian National Research Council (IFAC) to investigate the best sample that matches the dielectric value and obtain a general analysis of performance achieved in the microwave frequency range. The measurement data will be showed into a graph and compared between the same types of tissue and real human tissue. The samples were then analyzed in relation to the preceding publication and research paper. The samples were then analyzed over time to determine their life duration and changes in dielectric properties.

## 4.1 Results and analysis of the skin phantom

Several skin samples had been obtained during the period, and three were chosen for additional research. Table 4.1 shows the three final skin samples developed with various ingredients. Sample 1 has been produced with the fewest materials possible, and its physical qualities closely resemble genuine human skin due to its malleability. As a result, depending on the use, it can be shaped and thickened to the necessary extent. Aside from that, the phantom can be reused several times because it is reshapable; nevertheless, the phantom must be carefully preserved to ensure that the dielectric properties remain unchanged over time.

**Table 4.1: The development of the skin phantom samples.**

| | | |
|---|---|---|
|  |  |  |
| (a) Sample 1 | (b) Sample 2 | (c) Sample 3 |

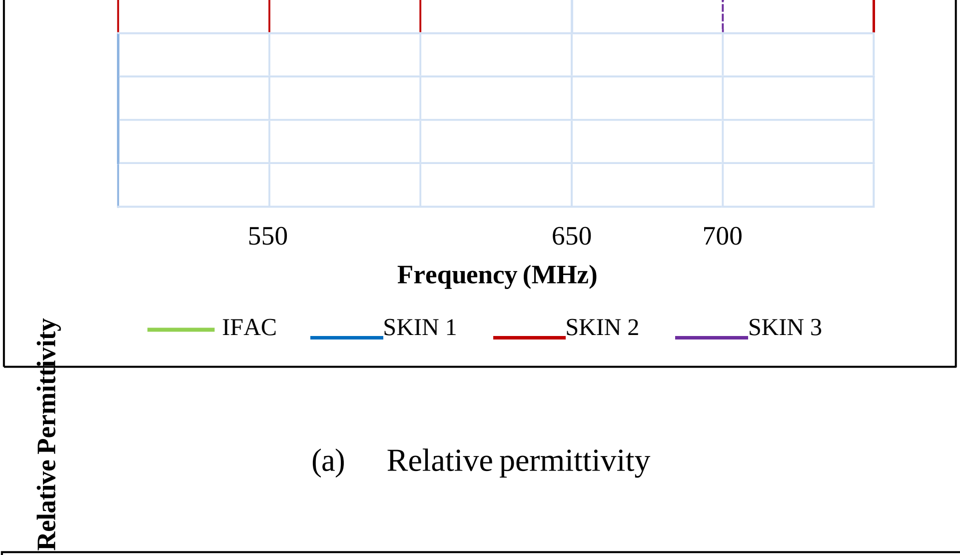


All skin phantom samples were measured to determine their dielectric properties, which included relative permittivity, conductivity, and loss tangent. Referring to Table 4.2, the samples' dielectric characteristics were initially tested at 500 MHz. Overall, all of the samples showed close to perfect agreement for relative permittivity, conductivity, and loss tangent values when compared to human tissue. However, sample 2 has substantial a similarity to real human tissue.

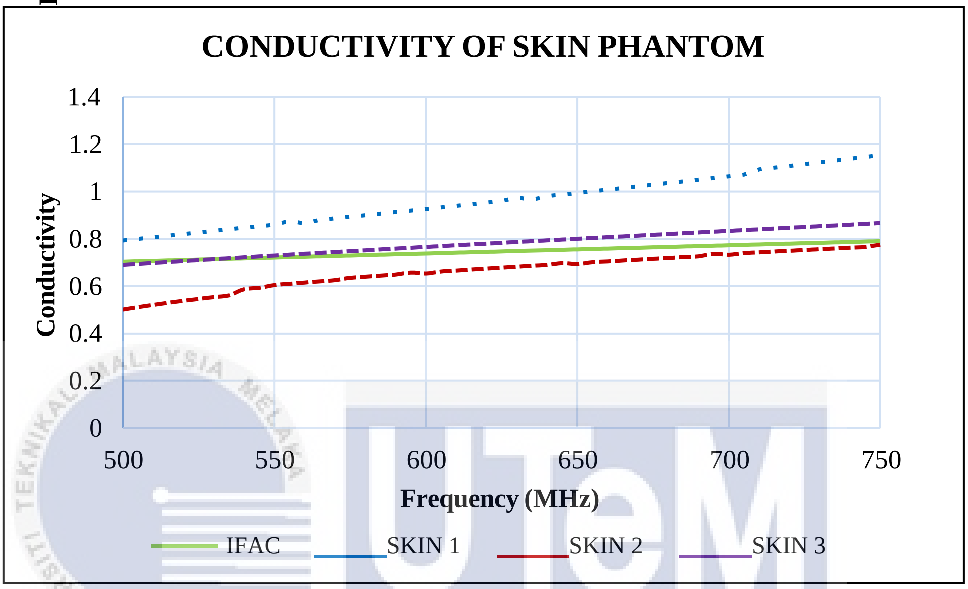
**Table 4.2: The dielectric properties comparison between human skin and the phantom samples at 500 MHz.**

| Samples/Parameter | Relative Permittivity | Conductivity | Loss Tangent |
|---|---|---|---|
| Human Tissue (IFAC) | 48.621 | 0.70444 | 0.52087 |
| Sample 1 | 61.9259 | 0.79334 | 0.652 |
| Sample 2 | 47. 9286 | 0.50212 | 0.6423 |
| Sample 3 | 46.8504 | 0.69062 | 0.5501 |

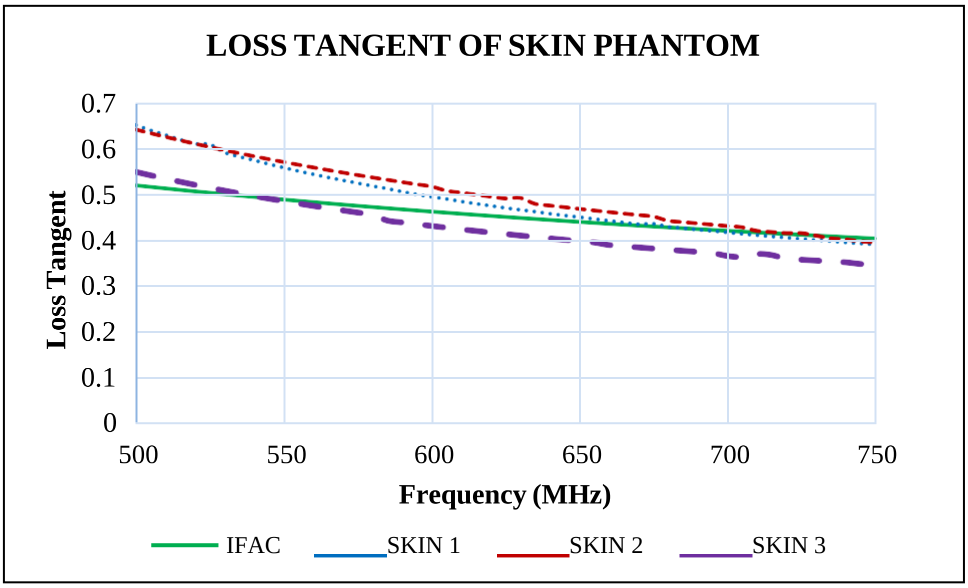
On the other hand, the frequency versus dielectric properties graph for each sample in the 500 MHz frequency range is shown in Figure 4.1 According to Figure 4.1(a), all of the samples are close in appearance to human skin, with the exception of Sample 2, which has particular similarities to human skin over the observed frequency range. Samples 1 have moderately higher frequencies and slightly higher mid frequencies. Sample 3 have similar relative permittivity to human skin at lower frequencies. Furthermore, a graph of frequency against conductivity is provided in Figure 4.1(b), which represents the conductivity for all samples, with Sample 3 showing a similar tendency to human skin and matching real human tissue in the lower frequency and slightly lower towards the high frequency. Although Samples 1 and 2 are not in line with the exact pattern of human skin conductivity, they are nearly identical in the lower and mid frequency ranges. Because Samples 1 and 2 did not exhibit the same trend, there is opportunity for improvement in which the conductivity can be improved by adding additional salt (NaCl) while simultaneously decreasing the value of real permittivity.




(a) Relative permittivity




(a) Conductivity




(c) Loss tangent.

**Figure 4.1: The comparison between human and skin phantom's samples (a) Relative permittivity, (b) Conductivity, (c) Loss tangent.**



## 4.2 Results and analysis of the fat phantom

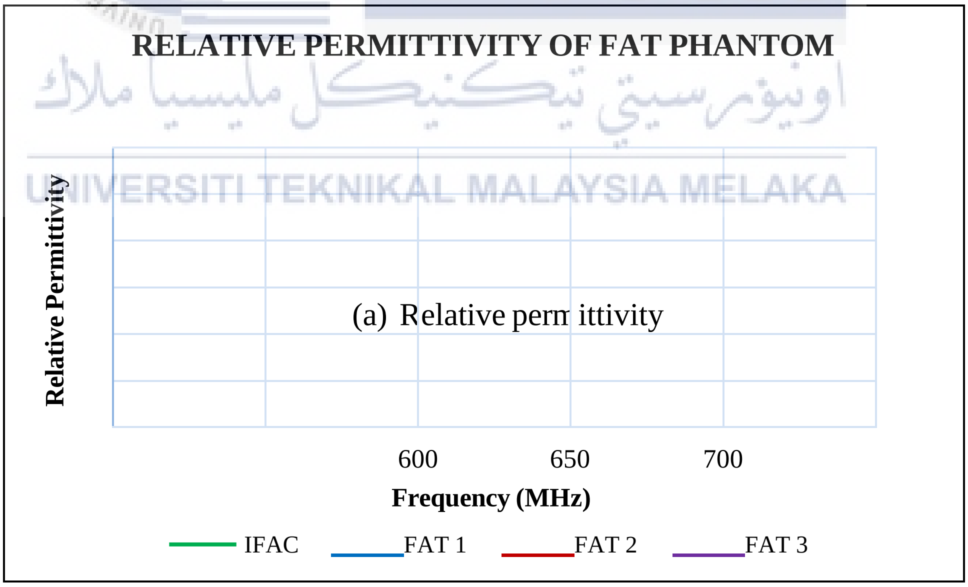
The fat phantom is well-known as a low-water phantom. The challenge in developing this phantom is to use minimal water as possible and to combine oil with additional materials. Table 4.3 shows three samples that were developed. Samples 1 and 2 were created using the same materials, with the sole difference being the addition of N-propanol to Sample 1. Both samples are agar-based, but Sample 2 was firmer and harder. Furthermore, Sample 3 has been produced with relatively few ingredients, and the texture is flexible.

**Table 4.3: The fat phantom samples development.**

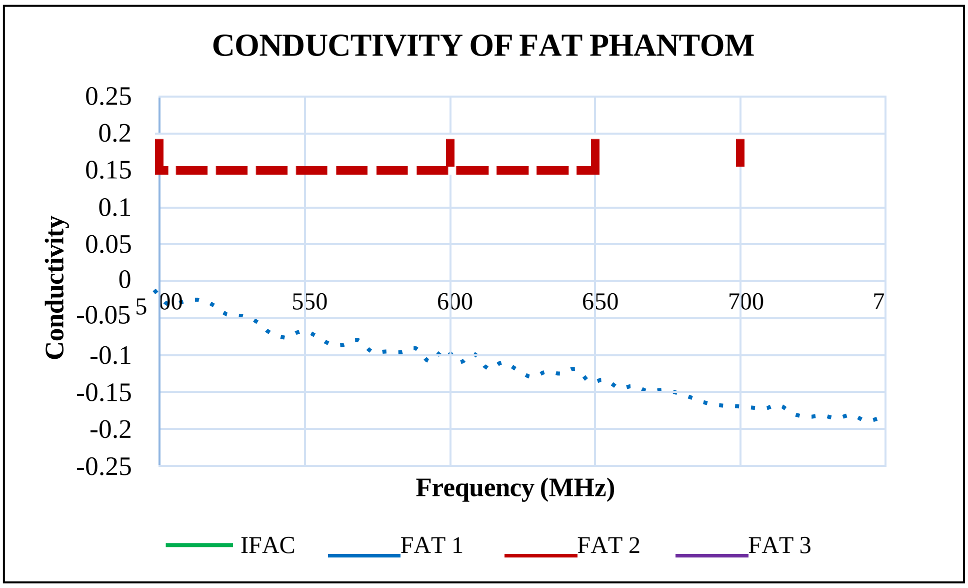
| | | |
|---|---|---|
| | | |
| (a) Sample 1 | (b) Sample 2 | (c) Sample 3 |

The dielectric properties of all samples for the fat phantom were measured at 500 MHz frequency. According to Figure 4.2(a), sample 3 had almost perfect to relative permittivity towards high frequency and a much larger value towards low frequency for Samples 1 and 2.

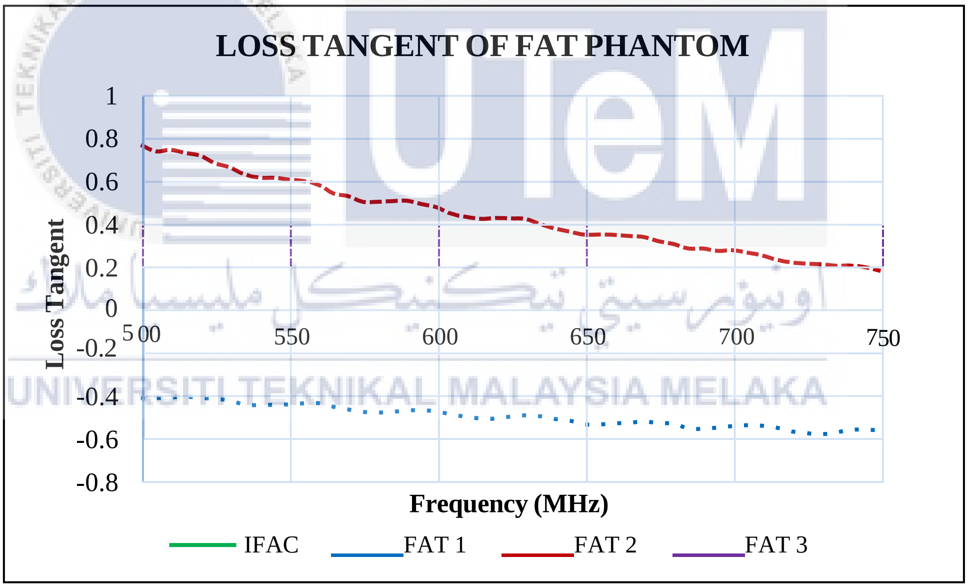





(a) Relative perm ittivity




(b) Conductivity




(c) Loss tangent

**Figure 4.2: The comparison between human and fat phantom samples (a) Relative permittivity, (b) Conductivity, (c) Loss tangent.**



This condition can be improved in the future by adding salt to lower the relative permittivity. However, the conductivity and loss tangent of Samples 1 and 2 do not follow the pattern of human fat. The complex permittivity should be enhanced by adding salt (NaCl). Only Sample 3 shows an essentially precise trend as human fat tissue in terms of relative permittivity over the frequency range. The conductivity decreases slightly as frequency increases, although it remains constant at low frequencies. This could be enhanced by using carbon powder. The loss tangent is lower than human fat at high frequencies due to the imaginary permittivity value, which can be enhanced with salt.

Table 4.4 illustrates the dielectric properties of all samples at 500 MHz. The relative permittivity of all the samples is nearly perfect, but only Sample 3 shows substantial similarities with only a 0.1.555 difference. Sample 2 and sample 3 differs significantly from the reference.

Sample 1 has a negative conductivity due to the imaginary epsilon value found in the raw data. Sample 3 has a loss tangent virtually identical to human fat, but Samples 1 are extremely low. Therefore, when compared to the dielectric properties of human fat tissue, Sample 3 shows the most significant near results.



**Table 4.4: The dielectric properties comparison between human fat and the phantom fat samples at 500 MHz.**

| Samples/Parameter | Relative Permittivity | Conductivity | Loss Tangent |
|---|---|---|---|
| Human Tissue (IFAC) | 5.5444 | 0.042793 | 0.27748 |
| Sample 1 | 3.8046 | -0.0118 | -0.408 |
| Sample 2 | 3.7641 | 0.15431 | 0.7715 |
| Sample 3 | 5.6999 | 0.033712 | 0.263 |

## 4.3 Results and analysis of the muscle phantom

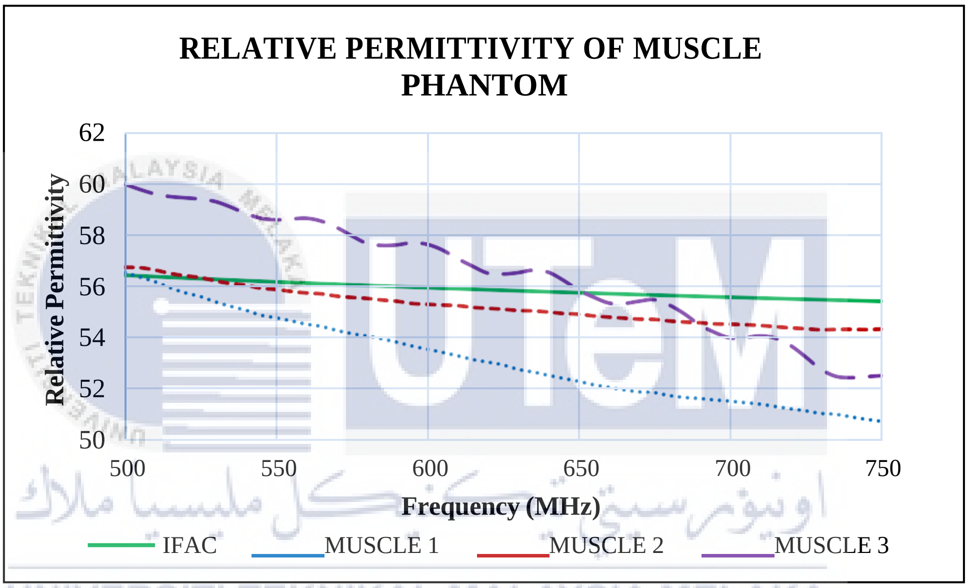
Numerous muscle phantom samples were produced effectively during the fabrication procedure. However, three samples were selected for additional analysis, as shown in Figure 4.3. The muscle phantom was placed in the refrigerator to conserve moisture following the creation process. All of the muscle phantom samples have the same physical characteristics, which are malleable and reshapable. The amount of chemicals required for developing the muscle phantom is fewer. Depending on the purpose, the phantom can be made to the necessary thickness.

**Table 4.5: The muscle phantom samples development.**

| | | |
|---|---|---|
| | | |
| (a) Sample 1 | (b) Sample 2 | (c) Sample 3 |

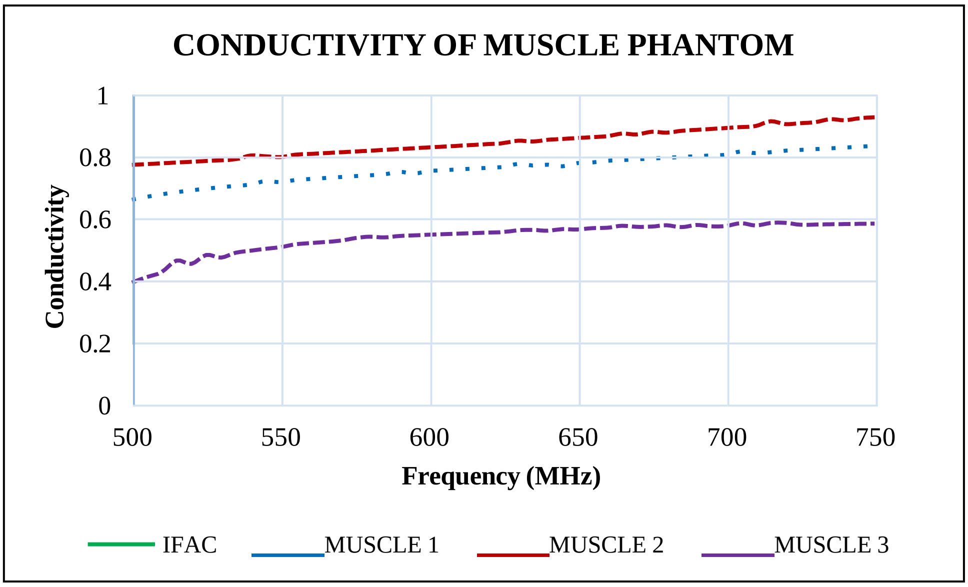


The phantom's dielectric properties were investigated, and the data gathered for 500 MHz was plotted onto a graph for better understanding during analysis. Figure 4.6 shows the relative permittivity, conductivity, and loss tangent for all samples. Sample 1 implies a similar trend to human muscle tissue, with near-perfect permittivity at high frequencies and very low permittivity at lower frequencies. Sample 3 has the lowest conductivity towards high frequency. At low frequency, the conductivity is comparable to human muscle. The loss tangent continues the same path as the human tissue, increasing in frequency and approaching proximity. Salt can be used to further improve the complex permittivity. Furthermore, Sample 2 has the same outcome as Sample 1, but at high frequencies, it perfectly matches relative permittivity. Otherwise, the trend is comparable to Samples 2 and 3, however Sample 1 has the most similar value to muscle tissue compared to the other samples.

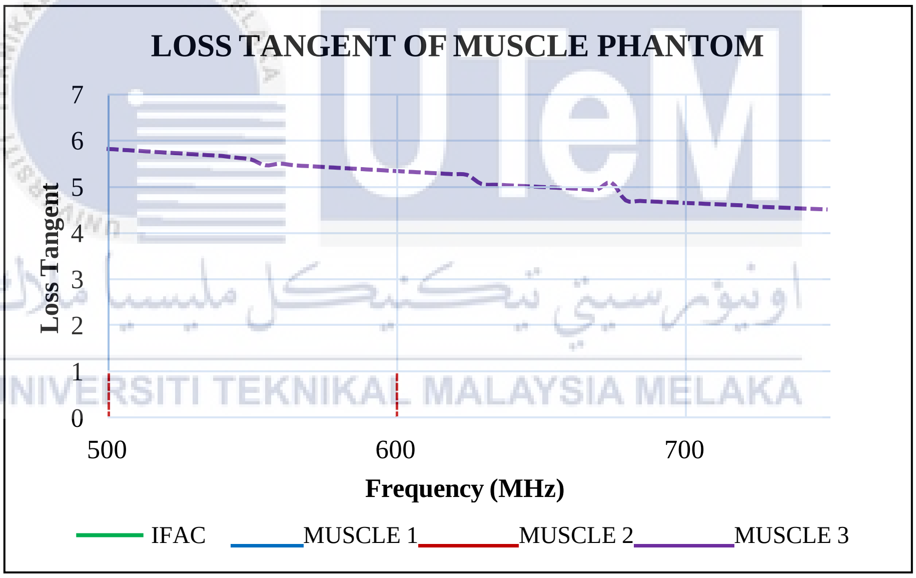





(a) Relative permittivity




(b) Conductivity






(c) Loss tangent

**Figure 4.3: The comparison between human and the muscle phantom samples (a) Relative permittivity, (b) Conductivity, (c) Loss tangent.**

Table 4.6 compares the dielectric properties of samples 1, 2, and 3 against those of human muscle tissue at 500 MHz. Samples 2 and 3 have nearly perfect relative permittivity, while Sample 1 is quite close to the human muscle. Samples 2 and 3 do not accurately represent human muscle conductivity, while Sample 1 does. Samples 1 and 3 have loss tangents that are almost identical to the reference muscle tissue.

**Table 4.6: The dielectric properties comparison between human muscle and the phantom muscle samples at 500 MHz.**

| Samples/ Parameter | Relative Permittivity | Conductivity | Loss Tangent |
|---|---|---|---|
| Human Tissue (IFAC) | 56.445 | 0.82245 | 0.52383 |
| Sample 1 | 56.5473 | 0.66398 | 0.5579 |
| Sample 2 | 56.755 | 0.7767 | 0.6068 |
| Sample 3 | 59.9962 | 0.39747 | 5.8249 |



## 4.4 Comparison of dielectric properties

Based on Table 4.7, the skin sample 2 and human tissue had some differentiate in relative permittivity as the result show the 0.6924 difference. Therefore, the skin sample 2 for both conductivity and loss tangent had a small gap between the IFAC [22] table which is 0.20232 and 0.12143 difference. It is causing the skin sample 2 have the best dielectric properties than skin sample 1 and skin sample 3. For the fat tissue, the fat sample 3 show the closer conductivity with the different 0.009081 to human tissue. Sample fat 3 also have nearly perfect relative permittivity and loss tangent that identical to the reference fat tissue in the Table 4.8 compared the other samples. The Table 4.9 compares the dielectric properties of muscle sample 1 against those of human muscle tissue in IFAC [22] table. Muscle sample 1 is quite close to the human muscle with only the 0.1023 difference in relative permittivity. Muscle sample 1 accurately represent human conductivity and loss tangent where it shows a small different and made it as nearly perfect sample that mimic the human tissue than another sample.

**Table 4.7: The dielectric properties different between sample skin tissue and the human tissue at 500 MHz.**

| Parameter/sample | Skin | | | |
|---|---|---|---|---|
| | **IFAC (a)** | **Sample 2 (b)** | **Δ = \|a-b\|** | **PE =** $\frac{Measure-Actual}{Actual}\|x100$ |
| Relative Permittivity | 48.621 | 47.9286 | 0.6924 | 0.01 % |
| Conductivity | 0.70444 | 0.50212 | 0.20232 | 0.4 % |
| Loss Tangent | 0.52087 | 0.6423 | 0.12143 | 0.19 % |

**Table 4.8: The dielectric properties different between sample fat tissue and the human tissue at 500MHz.**

| Parameter/sample | Fat | | | |
|---|---|---|---|---|
| | **IFAC (a)** | **Sample 3 (b)** | **Δ = \|a-b\|** | **PE =** $\|\frac{Measure-Actual}{Actual}\|x100$ |
| Relative Permittivity | 5.5444 | 5.6999 | 0.1555 | 0.002 % |
| Conductivity | 0.042793 | 0.033712 | 0.009081 | 0.24 % |
| Loss Tangent | 0.27748 | 0.263 | 0.01448 | 0.06 % |



**Table 4.9: The dielectric properties different between sample muscle tissue and the human tissue at 500 MHz.**

| Parameter/sample | Muscle | | | |
|---|---|---|---|---|
| | **IFAC (a)** | **Sample 1 (b)** | **Δ = \|a-b\|** | **PE =** $\frac{Measure-Actual}{Actual}\|x100$ |
| Relative Permittivity | 56.445 | 56.5473 | 0.1023 | 0.03 % |
| Conductivity | 0.82245 | 0.66398 | 0.15847 | 0.27 % |
| Loss Tangent | 0.52383 | 0.5579 | 0.03407 | 0.06 % |

## 4.5 Comparison of recent studies

To validate the previous results, the plot digitizer was used to extract the results from the most recent journal article. The JAWA programmed supports this software, which is used to digitize scanned functional data plots. This software allows for quick graph extract in image format, making it user-friendly. The image was submitted to the software, and the axis on the graph was calibrated. The maximum and minimum values for the x and y axes were declared. Later, the graph can be digitized by plotting the points along it. Once the graphing is complete, a set of data can be extracted and used for analysis. Sample 2, which has the closest value to real human skin, was compared to the most recent studies. Figure 4.4 compares the relative permittivity with respect to frequency between the Sample 2 skin phantom and recent journal studies [23][34]. It can be seen that all data follows a similar pattern to genuine human skin. REF [23] has a low relative permittivity at lower frequencies and similar permittivity to human skin at higher frequencies. REF [34] are almost identical to human skin. Sample 2 presents an approximation of perfect relative permittivity to human skin. In conclusion, Sample 2 has the closest relative permittivity to human skin compared to other previous studies.

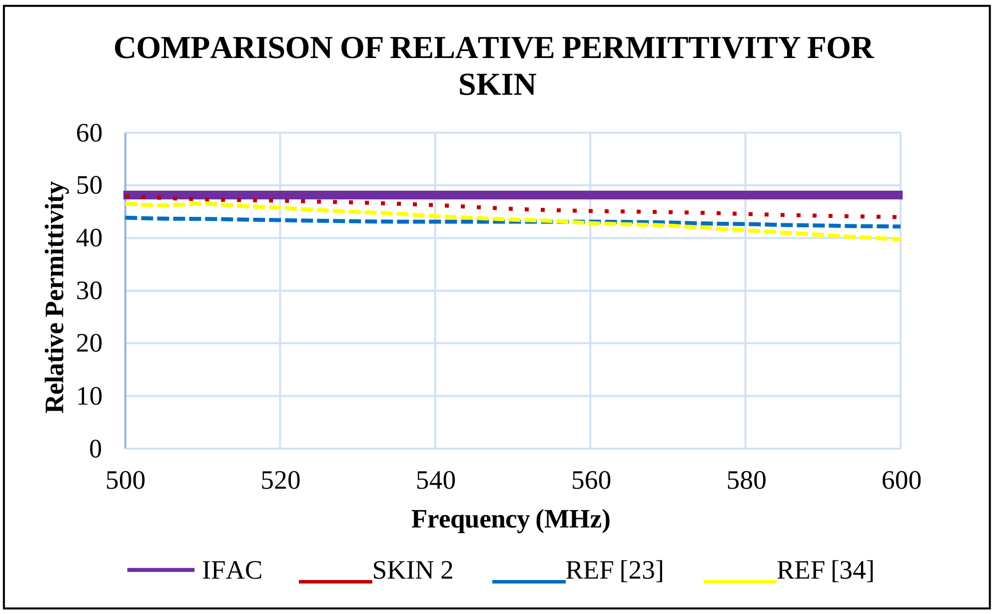



**Figure 4.4: The comparison of measured relative permittivity of skin phantom with recent papers.**



Figure 4.5 shows a graph comparing the relative permittivity values of fat samples compared to those in recent studies. Sample 3 and REF [34] are nearly identical to human fat, while REF [23] exhibits a similar pattern at low and high frequencies. Overall, when compared to human fat, the relative permittivity of Sample 3 and REF [34] is very similar.

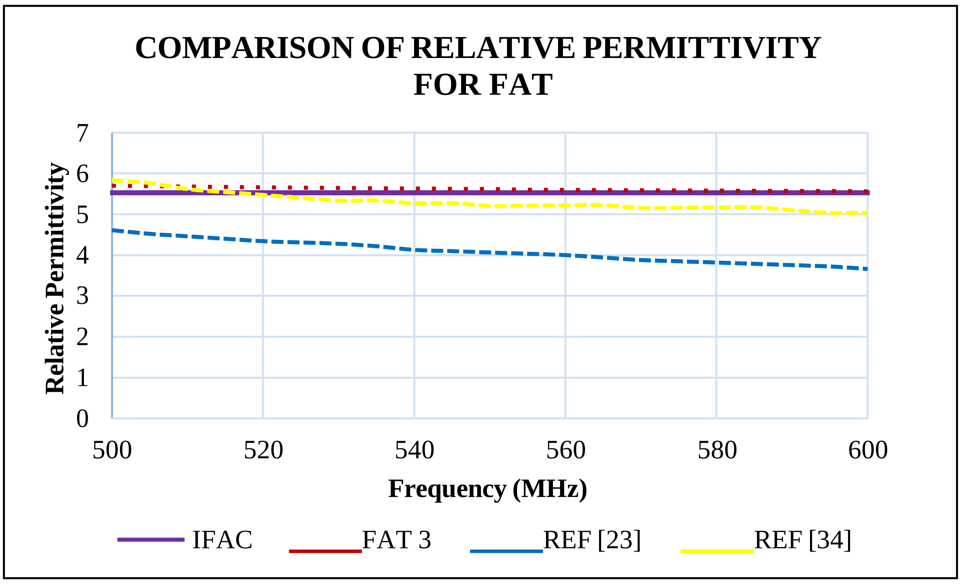



**Figure 4.5: The comparison of measured relative permittivity of fat phantom with recent papers.**



Figure 4.6 shows a graph comparing the relative permittivity values of muscle samples to those in recent studies. REF [34] states exceptional relative permittivity over the whole frequency band. REF [23] shows an almost similar to human muscle tissue within the frequency range of 500 MHz, whereas Sample 2 shows a perfect match to human muscle tissue. Finally, Sample 2 shows the closest value to human muscle tissue than REF [23] and REF [34].

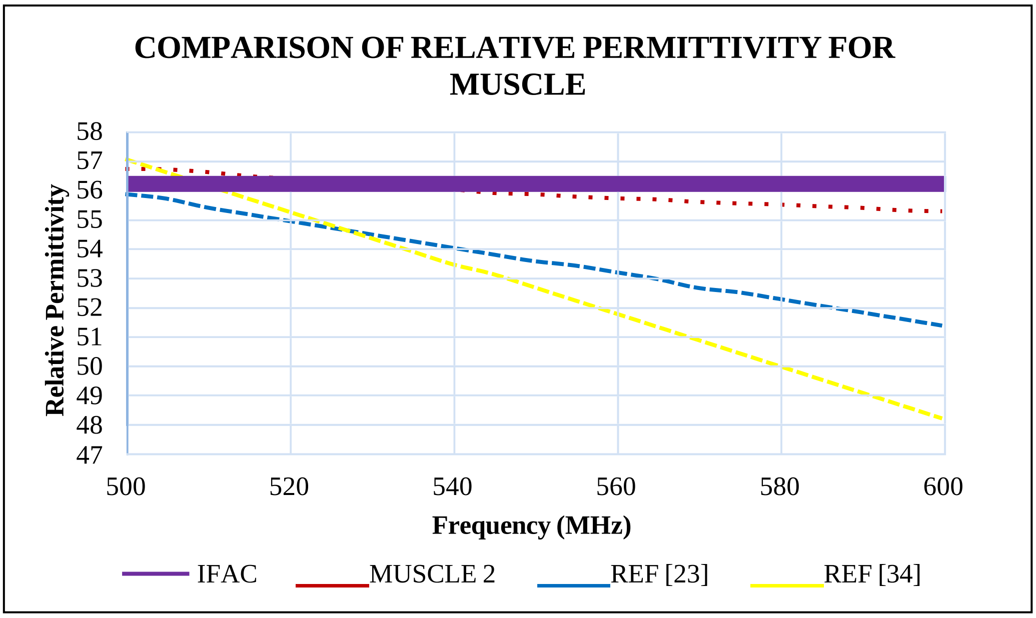



**Figure 4.6: The comparison of measured relative permittivity of muscle phantom with recent papers.**

# CHAPTER 5

# CONCLUSION AND FUTURE WORKS



## 5.1 Conclusion

Every year, more animals are being killed for testing or research purposes, and if this issue is not resolved, biodiversity will be lost. During clinical studies, humans are also subjected to hazardous ionizing radiations in order to test spectroscopic systems. To limit the negative influence on animals and humans, an innovative new method for measuring and testing throughout the research is required.

In this thesis, the development and characterization of a tissue equivalent phantom for microwave applications were discussed. In general, there are three varieties of phantoms: solid, semi-solid, and liquid. Due to its ability to replicate the physical characteristics of human tissue, the semi-solid phantom is the most suitable for creating phantoms of skin, fat, and muscle. The tissue-equivalent phantom can be used for spectroscopic research without the necessity for animal experimentation.

This study successfully developed a tissue-equivalent phantom that essentially replication the dielectric properties of human tissues within the chosen frequency bands. Accurate measurements validated the accuracy of the phantom's dielectric properties, assuring its dependability in replicating biological tissues. The tissue-equivalent phantom developed throughout this project was developed specifically for the microwave frequency range of interest (500 MHz – 1 GHz), compared to other phantoms that are made for larger frequency bands. This frequency specificity is essential for applications like medical imaging and hyperthermia treatment, which require precise dielectric properties.

A thorough investigation was carried out in order to select the most suitable ingredients and recipe to produce the tissue-equivalent phantom. Each of the ingredients that were utilized to generate the tissue phantom have a unique property that can vary the dielectric properties of the phantom when the amount employed in the recipe is varied. The majority of the ingredients utilized for producing the phantom are food-grade compounds that are readily available.



The achievement of the development and characterization of a tissue-equivalent phantom for microwave applications with frequencies ranging from 500 MHz to 1 GHz represents a significant step forward in ensuring the accuracy and dependability of microwave technologies in a variety of fields of study. This work enhances medical diagnostics, treatment optimization, and industrial applications by offering a foundational tool for researchers and practitioners working with microwave-based devices. The journey from recognizing the need for an enhanced tissue-equivalent phantom to its successful development and validation makes a significant contribution to the larger field of microwave engineering and biomedical applications.

## 5.2 Future work

The tissue-equivalent phantom was developed specifically for frequencies ranging from 500 MHz to 1 GHz. Future study could look into extending its applicability to a larger frequency band. Investigating dielectric characteristics outside the stated range may increase the phantom's flexibility for a wider range of microwave technologies.

The tissue-equivalent phantom has immense potential for calibrating and validating medical imaging equipment that operate at microwave frequencies. Further research could look into how to improve the accuracy and reliability of microwave tomography and radar-based imaging systems. The produced phantom's standardized and reproducible nature opens up possibilities for its usage in non-destructive testing and quality control in industrial applications. Further studies could investigate how the phantom improves the calibration and performance evaluation of industrial sensors.



Based on the findings of this research, a multi-layer skin, fat, and muscle phantom can be applied to generate an arm or leg phantom for testing purposes. This future study can be used to examine implanted devices since the results will be more dependable and realistic because the phantom structure resembles a real human hand or limb. Aside from physically developing the tissue equivalent phantom, three-dimensional (3D) printing is another method for developing tissue equivalent phantoms. The 3D printer allows consumers to produce unique prints for a variety of applications. Advances in 3D printing and imaging technology may enable the development of tissue equivalent phantoms capable of faithfully replicating the anatomical features and geometries of specific organs or tissues at low frequencies. If a tissue phantom is created with a 3D printer, numerous sorts of phantoms can be manufactured depending on the application.

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# APPENDICES

**APPENDIX A**

EvaChem

23G, Medan Bukit Indah 2, Taman Bukit Indah, 68000, Ampang, Selangor
Sales Line : 011-3741 2689

# Xanthan Gum

## Specification

**Trade Name** : **Xanthan Gum Food grade Mesh 80**

**Chemical Formula** : **(C35H49O29)n**

| Parameter | Standard |
|---|---|
| Appearance | White-Like or Light Yellow Powder |
| Particle size (mesh) | 100% through 60 mesh not less than 95% through 80 mesh |
| Viscosity (1% KCL cps) | >1200 |
| Sheer Ratio | ≥6.5 |
| V1/V2 | 1.02 – 1.45 |
| pH (1% solution) | 6.0 – 8.0 |
| Loss on Drying (%) | ≤15 |
| Ashes (%) | ≤16 |
| Pb (ppm) | ≤2 |
| Total Nitrogen (%) | ≤1.5 |
| Pyruvic Acid (%) | ≥1.5 |
| Total plate count (CFU/g) | ≤2000 |
| Moulds/ Yeast (CFU/g) | ≤100 |
| Coliform (MPN/g) | ≤0.3 |
| Salmonella | Absent |
| Ethanol (mg/kg) | ≤500 |

**APPENDIX B**

EvaChem

NAME OF PRODUCT: SODIUM BENZOATE

| | | |
|---|---|---|
| | | SPECIFICATION |
| CHARACTERS | A WHITE, ALMOST ODOURLESS, CRYSTALLINE POWDER OR PRILL | |
| IDENTIFICATION: | | |
| | BENZOATES | POSITIVE |
| | SODIUM | POSITIVE |
| APPEARANCE OF SOLUTION: | | |
| | CLARITY | CLEAR |
| | COLOUR | Y6 |
| ACIDITY OR ALKALINITY (ml/g): | | 0.2MAX |
| HALOGENATED COMPOUNDS: | | |
| | IONISED CHLORINE | 200 ppm MAX |
| | TOTAL CHLORINE | 300 ppm MAX |
| HEAVY METALS(IN TERMS OF LEAD): | | 10 ppm MAX |
| ARSENIC: | | 3 ppm MAX |
| LEAD: | | 2 ppm MAX |
| MERCURY: | | 1 ppm MAX |
| READILY OXIDISABLE SUBSTANCES | | POSITIVE |
| POLYCYCLIC ACIDS | | POSITIVE |
| LOSS ON DRYING % (m/m): | | 1.5% MAX |
| ASSAY % (m/m): | | 99.0%-100.5% |

ANALYZING METHOD ACCORDING TO BP2013,EP8.0, E211, USP38, NF33, FCC9

APPENDIX C

EvaChem

23G, Medan Bukit Indah 2, Taman Bukit Indah, 68000, Ampang, Selangor
Sales Line : 011-3741 2689

# Maltodextrin Specification

| Parameters | Specification |
|---|---|
| Appearance | White powder and no fixed shape |
| Smell | Has special smell of maltodextrin and no exceptional smell |
| Taste | Sweetness or slightly sweetness, no other taste |
| DE%(m/m) | 10-12 |
| Starch Test | Negative |
| Moisture%(m/m) | ≤6.0 |
| Solubility%(m/m) | ≥98 |
| pH | 4.6 – 6.5 |
| Ash%(m/m) | <0.6 |
| Iodine experiment | No blue reaction |

**Heavy Metal Analysis**

| | |
|---|---|
| As mg/kg | ≤1.0 |
| Pb mg/kg | ≤0.5 |
| Sulfur Dioxide g/kg | ≤0.04 |

**Microbiological Analysis**

| | |
|---|---|
| Total Plate Count | ≤3000 |
| Colinforms MPN/100g | ≤30 |
| Pathogenic Bacterium | No exist |

APPENDIX D

EvaChem

**23G, Medan Bukit Indah 2, Taman Bukit Indah, 68000, Ampang, Selangor**
**Sales Line : 011-3741 2689**

# Guar Gum

## Specification

| | |
|---|---|
| Moisture % | 9.33 |
| Ash% | 0.73 |
| Protein% | 4.02 |
| ACID INSOLUBLE MATTER% | 2.54 |
| Glactomannan % | 83.38 |
| Ph | 6.42 |
| **PHYSICAL ANALYSIS** | |
| Appearance | Light Cream Coloured homogeneous Powder |
| Granulometry<br>On 100 mesh % | NIL |
| Through 200 mesh % | 98.35 |
| **VISCOSITY (Brookfield)** | |
| 2 Hours | 5100 |
| 24 Hours | 5200 |
| ***MICROBIOLGICAL ANALYSIS*** | |
| Total Plate Count (cfu/g) | 1200 |
| Yeast & Molds (cfu/g) | 10 |
| Ecoli (cfu/g) | Absent |
| Salmonella (cfu/25g) | Absent |
| Starch | Absent |
| ***HEAVY METALS*** | |
| Arsenic | < 1 ppm |
| Lead | < 1 ppm |
| Mercury | ND |
| Cadmium | ND |
| Heavy Metals (As Pb) pm | < 2 ppm |

**Material has been passed from Metal detector**

BROOKFIELD VISCOSITY- Viscosity is measured at 1% solution , on Brookfield Viscometer RVT model using spindle no. 4 at 20 RPM, Temperature at@25°C.

Verified & Checked by:

APPENDIX E

Evacaely Enterprise

23G, Medan Bukit Indah, 68000, Ampang, Selangor

Sales Line : 011-3741 2689

# Specification Sheet

# Refined Glycerin 99%

| Paramater | Method | Specification |
|---|---|---|
| Glycerol Content %wt | APAG-GL-008 | 99.0% min |
| Moisture, % | USP 38 | 5.0 max |
| Color | USP 38 | 10 max |
| Chloride, ppm | USP 38 | 10 max |
| Sulphate, ppm | USP 38 | 20max |
| Fatty Acid & Esters (ml/0.5N NaOH/50g Glycerine) | USP 38 | 1.0 max |

APPENDIX F

***Food Ingredients Division***

*PRODUCT SPECIFICATION*

# Colloid Solution WJ-C1068
# (Carageenan Gum)

**Benefits**

- Completely soluble at 80-90°C
- Sparkling clear and transparent gel
- For instant application with boiled water

**Specification**

| | |
|---|---|
| - Moisture | 12% max |
| - Particle size | 60 mesh 80% pass |
| - Color | white to light yellow |
| - Viscocity (2.5% sol.,70°C) | 50-100 cP |
| - pH (1.5% sol.,25°C) | 7.0-10.0 |

**Bacteriological**

| | |
|---|---|
| - Total plate count | 3,000/g max |
| - Mold and Yeast | 100/g max |
| - Salmonella | Negative |
| - E. coli | Negative |

**Packing** : 25 kg/ ctn

**Storage** : store in cool and dry place, keep closing

**Dosage** : 2.5 g in 100 g water to form clear gel

APPENDIX G

EvaChem

## SPECIFICATION

( PURE DRIED VACUUM SALT,Food Grade )

| PROPERTIES | STANDARD |
|---|---|
| APPERANCE | FREE FLOW |
| Size 0.15-0.85mm(%) | 85%min |
| Sodium chloride(Nacl%) | 99.10min |
| Whiteness: | 80min |
| Moisture(%) | 0. 30max |
| Insoluble Matter(%) | 0. 05max |
| $CaSO_{4(\%)}$ | 0.10max |
| $Na_2SO_{4(\%)}$ | 0.30max |
| $[Fe(CN)_6]^{-4}$ | 10PPMmax |
| Ca | 0.03% max |
| Mg | 0.03% max |
| Cu | 10ppm max |
| Pb | 1.0PPM max |