



Faculty of Engineering

**Dielectric Property Analysis of Seafood Contaminants using Minkowski
Fractal Antenna**

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Dielectric Property Analysis of Seafood Contaminants using Minkowski Fractal Antenna

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DECLARATION

I declare that the work in this thesis was carried out in accordance with the regulations of Universiti Malaysia Sarawak. Except where due acknowledgements have been made, the work is that of the author alone. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.



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ABSTRACT

Malaysia's extensive coastline has abundant access to marine products such as fish, prawns, and other seafood. However, contamination of these marine products poses significant risks to food safety and public health, affecting both consumers and vendors. Contaminated seafood, often harboring pathogens like Salmonella and Vibrio, can lead to severe food poisoning depends on the concentration of these microbes. Mass spectrometers are high-precision instruments commonly used for detecting food contaminants. They can accurately identify and quantify various pathogens, pesticides, and toxins by analyzing the mass-to-charge ratio of ions. Despite their precision, the process from sample collection to result interpretation can take 6 to 24 hours and the high cost of these devices limits their accessibility for smaller laboratories and food producers. To address these limitations, this study explores the use of the Minkowski Fractal Antenna as a cost-effective and non-destructive alternative for food contamination detection. Several tests have been conducted to demonstrate the validity of the Minkowski Fractal Antenna as a resonator. The results shows that the designed Minkowski Fractal Antenna serves as a resonator where it can detect differences in return loss results when dispersed in solutions with seafood contaminants, offering a cheaper alternative to commercialized methods.

Keywords: Microstrip patch antenna, Minkowski Fractal Antenna, bandwidth, impedance, frequency

Analisis Sifat Dielektrik Bahan Pencemar Makanan Laut Menggunakan Antenna Fraktal Minkowski

ABSTRAK

Pantai yang luas di Malaysia memberikan akses kepada kepelbagaian produk marin seperti ikan, udang, dan makanan laut lain. Walau bagaimanapun, pencemaran produk marin ini menimbulkan risiko yang signifikan terhadap keselamatan makanan dan kesihatan awam, yang melibatkan pengguna dan juga penjual. Makanan laut yang tercemar, yang sering mengandungi patogen seperti Salmonella dan Vibrio, boleh menyebabkan keracunan makanan yang teruk bergantung kepada kepekatan mikrob ini. Spektrometer jisim adalah instrument berketepatan tinggi yang biasa digunakan untuk mengesan pencemaran makanan. Alat ini boleh mengenal pasti dan mengukur pelbagai patogen, racun perosak, dan toksin dengan menganalisis nisbah jisim kepada cas ion. Walaubagaimanapun, proses dari pengumpulan sampel hingga interpretasi hasil boleh mengambil masa 6 hingga 24 jam dan kos tinggi proses ini menghadkan kegunaannya terhadap makmal kecil dan pengeluar makanan. Untuk menangani masalah ini, kajian ini meneroka penggunaan Antena Fraktal Minkowski sebagai alternatif yang lebih kos efektif dan tidak merosakkan proses pengesanan pencemaran makanan. Beberapa ujian telah dijalankan untuk menunjukkan keberkesanan Antena Fraktal Minkowski sebagai resonator. Hasil ujian menunjukkan bahawa Antena Fraktal Minkowski yang direka berfungsi sebagai resonator di mana ia boleh mengesan perbezaan dalam keputusan kehilangan pulangan apabila tersebar dalam larutan dengan pencemaran makanan laut, menawarkan alternatif yang lebih murah berbanding kaedah komersial.

Kata kunci: *Antenna tampalan jalur mikro, Fraktal Minkowski Antenna, jalur lebar, impedans, frekuensi*

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LIST OF ABBREVIATIONS

S-parameter	Scattering-parameter
S_{11}	Scattering-parameter from port 1 reflected back
S_{22}	Scattering-parameter from port 2 reflected back
S_{12}	Scattering-parameter from port 1 to port 2
S_{21}	Scattering-parameter from port 2 to port 1
P_1	Port 1
P_2	Port 2
P_3	Port 3
P_4	Port 4
Δ, α	Difference
Z_0	Initial impedance
λ	Wavelength
$\lambda/4$	Quarter-wavelength
$\lambda/4$ Z_s, Z_T	Characteristic Impedance
Z_a, Z_b ϵ_r	Dielectric constant
GHz	Giga Hertz
mm	Millimetre

Ω	Ohm
C	Coupling value
λ_f	Operating frequency wavelength
c	Speed of light
f_0	Operating frequency
w_p	Microstrip patch width
w_h	Microstrip height
π	Pi
θ	Electrical length

CHAPTER 1

INTRODUCTION

1.1 Research Background

Malaysia, one of the sea-encircled nations in Southeast Asia, has a lengthy coastline that is 4,809 km long and 329,750 km squared in the area which leads to the convenient access of getting seafood products such as fishes, prawns and etc. However, contamination of seafood product has always been a crucial problem for both customers and suppliers as it leads towards food safety and public health (Ali et al., 2020).

Contamination in seafood product is common sources of infection and disease. The presence of microorganism such as Salmonella, Vibrio spp. and heavy metals need to be evaluated to ensure the food is still in the safe stage to be eatable. Based on the literature, it is said that the seafood product must not contain any Salmonella and Vibrio spp. If there is a presence of these microorganisms in the seafood product, it is said the seafood product is contaminated. The level of Salmonella and Vibrio that contaminated the seafood product affect the severity of food poisoning (Blakey et al., 2012).

Rapid screening technique can be used at the early stage to remove unwanted sample from the shelf in the supply chain before proceeding to confirm the analysis for quality test. One of the methods for screening technique is vibrational spectroscopy. The advancement in vibrational spectroscopy in terms of measurement speed and the minimal disposal of waste has gained interest in research, control, and industrial laboratories (Moros et al., 2010). The common implementations in research work related to food application, pharmaceutical industry, and others are food moisture sensor, metal detector food product, mid-infrared (MIR) and near-infrared (NIR) techniques (Meng et al., 2017).

Up till now, the accurate devices or techniques to detect the level of contamination in the seafood product have always been a serious challenge. Various numbers of technologies have been used to evaluate the quality of seafood product such as food moisture sensor, metal detector for food product and in-line Near-Infra-Red (NIR) analyser (Meng et al., 2017). Although the precision of these technologies is high, they were too, expensive, time-consuming (where for the biological method, it takes up to 6 to 24 hours), complicated and sometimes, hazardous (Uan et al., 2004).

Fourier Transform Near-Infrared Spectroscopy or also known as (FT-NIR) is a non-destructive chemical analysis technology that is used to identify and analyze numerous materials. FT-NIR have a stable with better wavelength accuracy, higher resolutions, and signal energy (Bag et al., 2011). Proper measurement technique should be done to reach an optimum result. Therefore, by using the microstrip patch antenna (MPA), a low cost and non- destructive testing and evaluation device can overcome several weaknesses in the technologies abovementioned.

Over the years, MPAs have been extensively employed in a variety of fields, including communications, aquaculture, agriculture, and medicine. MPA has been used in agriculture to measure the moisture content of Hevea rubber latex (Yahaya et al., 2014). In addition to moisture content, MPA can also be used to assess temperature, oil, salinity, bulk density, and sugar.

Thus, MPA was used in this project due to its ability to detect the changes occurred in dielectric properties based on its relationship with resonant frequency location. In Gharbi et al. (2021), MPA is used to detect the level of salinity and sugar in the water. As the salt and sugar been added into the pure water, the composition of the molecule is changing where additional

impurities lead to the degradation of the polarization and this create a different dielectric property that change the dielectric constant and Q factor value.

Also, in Islam et al. (2018), the author comes out with a conclusion that as the water been added with impurities such as salt and sugar, the polarization of the pure water molecules has been decreased that lead to affecting the value of the dielectric properties and dielectric constant. In the four experimental data samples shown in this paper, it can be concluded that the reflection coefficient has been decreasing for all samples. This is due to the same reason in Gharbi et al. (2021) where the additional impurities reduced the amount of polarization and conductivity.

Studies by Octavianti and Jaswir (2017) were made based on the variation of different dielectric properties of the liquids including ethanol. The studies focus on the changes in height, permittivity, and conductivity of the medium. The outcome stated that two of the studies is related to the changes in the level of dielectric properties in the medium.

Another research on relative dielectric permittivity measurement for a solvent such as ethanol, methanol, and dimethylsulphoxide is done in Huang et al. (2012), where the method is based on capacitive perturbation of resonator. It turns out that the dielectric permittivity is related to the resonant frequency of the solvent.

This thesis introduces the Minkowski fractal antenna within the context of microstrip patch antennas, highlighting its potential to enhance performance through innovative design. The Minkowski fractal geometry enables the creation of antennas that exhibit compact size, and improved radiation efficiency. By incorporating these fractal patterns into microstrip patch antennas, we can achieve superior bandwidth and miniaturization, addressing the growing demand for space-efficient solutions in wireless communication.

Therefore, the primary goal of this study is to design, carry out, and compare the analysis of the Minkowski Fractal Antenna, used as a resonator as a preliminary step to remove undesirable samples from the shelf in the supply chain before moving on to confirm the analysis for a quality test. Four iterations of Minkowski Fractal Antenna have been designed and fabricated. The results on the reflection coefficient (S_{11} parameter), Voltage Standing Wave Ratio (VSWR), bandwidth, impedance, gain, efficiency, and current distribution are displayed.

1.2 Problem Statement

Fishing industry in Malaysia plays a significant role in country's economic development as it is one of the sources of employment, foreign exchange, and protein supply. The most important seafood in Malaysia is fish as it contributes 85% of total seafood production. Organic contamination, oil and grease, and heavy metals are main sources that pollute Malaysian rivers. These pollutants must be controlled to make certain that the marine environment is not polluted and harmful for consumptions. Contamination of the seafood products lead to foodborne illness that has always been a crucial problem for both customers and suppliers as it leads towards food safety and public health.

Foodborne illness or food poisoning is an illness from consumption of food spoiled by pathogenic bacteria, viruses, parasite, and other contaminants (Ali et al., 2020). The level of Salmonella and Vibrio that contaminated the seafood product affect the severity of food poisoning (Nakaguchi, 2013). Thus, the presence of microorganism such as Salmonella, Vibrio spp. and heavy metals need to be evaluated to ensure the food is still edible. Fisheries Development Authority of Malaysia (FDAM) is the government body in charge of increasing production and monitoring national fish supply's sufficiency and compliance with key regulatory criteria.

Different wet chemistry methods, such as mass spectrometry, gas chromatography and High-Performance Liquid Chromatography (HPLC) techniques can be done to determine the seafood product quality (Cherta et al., 2015). Unfortunately, although the methods mentioned above are precise, it is time consuming, required skilled technicians and involve a lot of laboratory procedures, solvents, glassware, and disposal of reagents which need to be done cautiously (Artavia et al., 2021). It is time-consuming, wasting resources and money to send the samples for further investigation without preliminary indicator if the samples turn out to be genuine.

A low cost, non-destructive testing and evaluation antenna resonator should be designed for the best measurement result. Antenna is appropriate for testing and evaluation of FT-NIR exposure level which is specifically set at frequency of ISM band where up to 3 GHz. These frequencies are in Ultra High Frequency (UHF) and Very High Frequency (VHF) band region of the RF spectrum which is allocated for communication signals coming from all directions (Islam et al., 2018).

Even though there are various research has been done by using MPA to study on the changes of dielectric properties, however, most of the literature focus on the molecules occurred in liquid or solvent such as oil, water, and alcohol. None of the research focuses on the changes in dielectric properties in seafood product.

Traditional MPA also often lack the sensitivity required to detect low levels of contaminants in seafood, posing a risk to public health. Many existing microstrip patch antennas are constrained to narrow frequency bands, which may hinder their effectiveness in identifying a broad spectrum of seafood contaminants. The increasing demand for portable seafood testing solutions necessitates compact and efficient antenna design. Current seafood

contaminant detection methods often do not support real-time monitoring, resulting in delayed responses to contamination.

The analysis of seafood contaminants poses significant challenges due to the limitations of traditional detection methods, which often lack the sensitivity and specificity required for effective monitoring. This thesis addresses the critical problem of ensuring food safety by investigating the application of Minkowski fractal antennas for the detection of harmful substances in seafood. These antennas have the potential to enhance the accuracy and efficiency of contaminant analysis. The research aims to evaluate the effectiveness of these antennas in real-time detection scenarios, ultimately contributing to improved food safety measures and public health protection. The exposure data could be used for future studies to overcome several weaknesses in the technologies abovementioned.

1.3 Objectives

The following objectives of this project are stated as follows:

- i. To design, simulate and fabricate four iterations of Minkowski Fractal antenna that can be used as a resonator.
- ii. To investigate the relation between dielectric properties and resonant frequency under the influence of non-pure solution and microorganism/chloramphenicol of the seafood product.
- iii. To compare the performance of Minkowski fractal antennas with traditional antenna designs, such as square patch antennas, to highlight their advantages in specific applications.

1.4 Scope of Research

This research focus on the design and development of a cost-effective microstrip patch antenna intended to function as a sensor, with the Minkowski Fractal antenna selected for this study. The antenna designed for operation within the ISM (Industrial, Scientific, and Medical) frequency band. The substrate material utilized for this patch antenna Rogers RO4003C. Several formulas employed to facilitate the design calculations within CST Microwave Studio. It is essential that the simulation results adhere to the specified design parameters prior to fabrication, ensuring that the microstrip patch antenna is capable of accurately measuring the dielectric properties and resonant frequency of seafood products. Following successful simulation validation, the microstrip patch antenna fabricated and subsequently validated using a Vector Network Analyzer (VNA) to confirm its suitability as a resonator sensor for the research project. Upon successful validation, the antenna undergoes experimental testing with salt and sugar solutions to ensure operational effectiveness, as well as solutions containing Chloramphenicol.

1.5 Research Motivation

The increasing global concern over food safety, particularly in seafood, necessitates innovative detection methods to ensure consumer health and prevent foodborne illnesses. The growing prevalence of seafood contamination and its associated health risks underscore the critical need for reliable detection methods in the food industry. Current practices often lack the required sensitivity and immediacy, leaving consumers vulnerable to foodborne pathogens. Traditional detection techniques often fall short in terms of sensitivity, speed, and efficiency, highlighting the urgent need for advanced solutions. This thesis is motivated by the potential of Minkowski fractal antennas to revolutionize contaminant analysis in seafood. Their unique design offers compact size, and improved signal sensitivity, making them ideal for real-time

monitoring of harmful substances. By exploring the application of these antennas, this research aims to contribute to the development of more effective food safety technologies, ultimately enhancing public health and confidence in seafood quality.

1.6 Thesis Outlines

This thesis is organized into five chapters: Chapter 1 serves as the Introduction, Chapter 2 presents the Literature Review, Chapter 3 outlines the Methodology, Chapter 4 discusses the Results and Analysis, and Chapter 5 concludes with Findings and Future Work.

In Chapter 1, the introduction provides a background to the research, articulates the problem statements, and outlines the objectives and scope of the project. Chapter 2 delves into the literature review, beginning with an overview of microbial contamination in seafood products and the application of microwave sensor technologies for assessing food quality. This chapter also includes a discussion on antennas, covering their characteristics such as bandwidth, directivity, gain, input impedance, radiation efficiency, radiation pattern, polarization, return loss, and voltage standing wave ratio (VSWR). Additionally, it addresses the four feeding techniques: microstrip line feed, coaxial probe feed, aperture coupling, and proximity coupling. Given that this study focuses on microstrip antennas for detecting marine products, a brief introduction to the methodology of microbiological testing is also included.

Chapter 3 discusses the project methodology, emphasizing the processes employed to complete the research. A flowchart illustrates the organization and timeline of the project. This chapter also presents the formulas used for calculating key parameters and details the specific steps and methods implemented in the design proposal.

Chapter 4 presents, analyzes, and discusses the results obtained from the simulated and fabricated patch antenna. The analysis of the fabricated microstrip patch antenna included, along with comparisons of different feeding techniques. Furthermore, this chapter detail the analysis of the Minkowski Fractal Antenna, including its resonant frequency and reflection coefficient.

Finally, Chapter 5 summarizes the overall findings of the project and includes recommendations for future research.

CHAPTER 2

LITERATURE REVIEW

2.1 Overview

Literature review on microbial contamination and microbiological examinations of seafood products introduced in this chapter. Also, resonator and antenna theory discussed. Besides that, the techniques to improve the performance of microstrip patch antenna also be concluded in this chapter which includes reflection coefficient and dielectric constant.

2.2 Introduction

At every level of the food manufacturing process, food quality and composition are crucial factors to consider. For a long time, theories and tools for evaluating food by identifying its dielectric characteristics and behaviors have been of interest (Ali et al., 2020). The advantages of microwave sensors compared to other technologies include their non-destructive nature, capability to examine internal structures, and lack of contamination. Consequently, measuring permittivity across various applications has been extensively researched to assess specific properties of food ingredients (Nakaguchi, 2013).

Due to the wide frequency range of microwave (300MHz- 300GHz), the diversity in measurement approaches (reflection, transmission, and resonation), and the extent of microwave techniques (frequency and time domains, continuous wave and UWB pulse, single antenna and antenna array etc.), measurement methods can be flexibly customised to suit the requirements. Studies suggest that many deteriorative biochemical and microbiological processes that take place during the gradual spoilage of food materials have a remarkable influence in the microwave frequency region (Cherta et al., 2015). As a result, microwave

technology is being employed more and more for tasks including quality assessment (Artavia et al., 2021), freshness and storage life (Moros et al., 2010), component determination (Meng et al., 2017), composition analysis (Bag et al., 2011), contaminant analysis (Islam et al., 2018), and structure monitoring throughout the aging process (Khan & Nema, 2012), among others.

One of the most commonly employed techniques in microwave technologies is frequency domain dielectric spectroscopy. Most reported studies have been conducted in laboratory settings using specialized equipment (Ali, 2007). Additionally, time domain measurement tools have been developed to evaluate the dielectric properties of food. Industrial instruments, including portable and compact devices, are now emerging in the market (Sultan et al., 2019). Recent advancements in microwave components, smart sensors, and related information and communications technology (ICT) have significantly enhanced the potential for microwave sensors in the food industry.

Modern monolithic microwave integrated circuit (MMIC) components hold great promise for innovative microwave sensor systems by miniaturizing size, reducing power consumption, and lowering costs. Several commercial ultra-wide-band (UWB) components enable the extraction of extensive spectrum data by generating measurement-ready nanosecond pulses with a single compact system on chip (SoC) unit. Furthermore, as information technologies advance, new concepts for sensor module designs have emerged to address the needs of evolving industries, where flexible data access, communication, and collaborative automation are crucial for the advancement of smart manufacturing.

Recent advancements in microwave technology and reductions in costs have facilitated the development of a range of innovative applications, such as presence detection, indoor positioning, and respiratory monitoring. Nevertheless, most research on microwave sensors for

food evaluation has been conducted in laboratory settings. This highlights a critical need for further exploration in this area, particularly given the scarcity of rapid and cost-effective solutions for the food industry and the progress of associated enabling technologies.

2.3 Microbial Contamination in Seafood Products

Seafood products have been reported to be healthy diets due to the high polyunsaturated fatty acids and essential trace elements (Huang et al., 2012). As a result, many coastal countries such as Malaysia have encouraged seafood farming to meet local and international needs. Seafood that has been contaminated may include diseases. Similar to that, seafood that has pathogens might not be accepted for export. As an illustration, Malaysia was among the nations whose seafood and seafood-related products were confiscated by European nations due to the presence of antibiotics (Butt et al., 2004).

Malaysia was one of the four Southeast Asian nations, along with Thailand, Vietnam, and Indonesia whose seafood goods were rejected by 19 European nations between 1997 and 2020 due to viruses, according to a new study (Rappaport et al., 2015b). Antibiotic resistance and seafood-borne infections are both regarded as global health issues because they pose a danger to food security.

Over 30,000 fatalities are believed to occur each year in Europe as a result of antibiotic-resistant infections (Butt et al., 2004b). Additionally, it was anticipated that by 2050, antibiotic-resistant diseases would result in 10 million deaths annually worldwide, which might result in a 2% to 5% (USD 100 trillion) decline in gross domestic product. Numerous studies have documented the prevalence of infections associated with seafood in Malaysia. The diversity of microorganisms that are antibiotic-resistant in seafood and the antibiotics to which they are resistant are unknowns, as is the estimated pool prevalence.

2.4 Microwave Sensor Technology for Food Quality Evaluation

For wholesalers and dealers of fresh fish and marine products, consumer approval and food safety are top priorities. Fish and fish products are popular all over the world and play a significant part in a balanced diet for people, as they offer a variety of nutrients and health advantages (including protein, omega-3 fatty acids, and vitamins). Fresh fish and fish products, on the other hand, are extremely perishable foods that are prone to rapid odor and flavor development as well as rapid decomposition. This is a result of their biological make-up as well as a number of physical and chemical traits: low connective tissue content, the presence of autolytic enzymes, neutral pH, and high-water activity. The shelf life of fresh fish is determined by the interval between its creation and spoilage brought on by biochemical processes and microbial activity (Oliveira et al., 2020b). Fish quality can degrade through a process called spotting, which affects the fish's appearance, flavor, aroma, and texture of the meat. After a brief initial period of spoiling, an increase in pH and nitrogen-containing chemicals leads to the expansion of bacteria, which affects the color of the eyes, the surface of the body, the abdomen, and the tone of the muscles.

To evaluate fish quality and spoilage effectively, reliable methodologies and techniques are essential. Sensory qualities such as appearance, colour, texture, odour, and taste are key factors in determining fish quality. Several sensory characteristics, including the brightness of appearance, meat colour, gill colour, meat firmness, and aroma, can be utilized to assess freshness based on variations in these attributes (Bjarnadottir et al., 2015). The Quality Index Method (QIM) is the most widely adopted approach for sensory evaluation, focusing on sensory quality attributes related to the skin, eyes, gills, and abdomen of raw fish. Although this method, developed for specific fish species, requires supplementary techniques, it is

commonly employed to measure fish quality due to its emphasis on factors that significantly change throughout the product's shelf life (Castro-Giráldez et al., 2010).

To evaluate the freshness and quality of fish, quantitative chemical and physical methods are linked to sensory parameters. Sensory parameters refer to the attributes that can be perceived through the senses, such as appearance, colour, texture, odour, and taste. In the context of evaluating fish freshness and quality, these parameters provide crucial insights into the fish's overall condition and palatability, often guiding consumer choices and safety assessments. Quantitative chemical and physical methods help quantify these sensory attributes to ensure accurate evaluations. Chemical characteristics are connected to biochemical alterations that take place in a fish after it is harvested. Specific spoilage organism (SSO) growth, lipid oxidation, peroxide value (PV), and the K value based on adenosine triphosphate (ATP) degradation are some of the criteria that are most frequently employed (Clerjon & Damez, 2007). Fish freshness could be evaluated using physical characteristics as texture, electrical, and optical metrics chemical and physical characteristics are closely related to sensory characteristics, but they are also influenced by a number of variables, including species, age, proximate composition, fishing region, season, and animal nutrition.

Pérez-Rodríguez et al. (2013), discusses the limitations of conventional quality evaluation methods, including costs and expertise requirements. The paper discusses various emerging technologies, including electronic noses, spectroscopic techniques, and biosensors, which offer faster and more reliable alternatives for evaluating freshness and quality. These technologies time consuming, which is also a drawback because seafood product must frequently be sold the same day they are killed because of how quickly they spoil. The faster,

more affordable, and non-invasive sensing approaches, except for biosensors, could solve these issues and enable on-line detection (Alahnomi et al., 2021b).

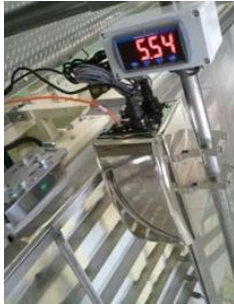
2.4.1 Food Sensor Technologies

The commonly referenced definition of food quality is a combination of attributes or characteristics of a product that are significant in determining its acceptability to consumers. This definition can be used to describe the phrase food quality.

External characteristics including appearance (size, shape, color, gloss, and consistency), texture, flavor, and internal composition (chemical, physical, and microbiological) are some examples of these properties. Chemical, microbiological, metabolic, and physical reactions are the most significant quality-related alterations. Food quality changes throughout time, and quality indicators are not consistent.

As a result, measuring food quality at all phases of manufacturing, storage, and transportation is crucial. The core purpose of food quality sensors is to monitor changes in quality utilizing sensor technologies, with a particular emphasis on sensing physical and chemical attributes.

Figure 2.1 depicts several examples of sensor devices used in contemporary industry for online applications. Online quality assessments can be performed using near-infrared (NIR) data of food products and other variables such as food moisture content, metal in meat products, and sensor technologies (Bag et al., 2011b).



(a)



(b)



(c)

Figure 2.1: Food Quality Evaluation Sensors (a) Food moisture sensor (b) Metal detector for meat products (c) In-line NIR analyser (Bag et al., 2011b)

Many other sensor technologies available in the market that can potentially be applied for food evaluation and analysis. The commonly used methods are summarized in Table 2.1.

Table 2.1: Sensor technologies can be potentially applied for food evaluation and analysis

Technologies	Advantages	Disadvantages	Paper
Ultrasound spectroscopy	Contact/contactless, quick, precise, affordable, simple system	Low spatial resolution or absence of spatial information	Zhao et al. (2018)
Fibre optical biosensor	High sensitivity and specificity, contactless, non-destructive, compact design, and remote monitoring	Long response time, poor spatial resolution, and no spatial information	Zhang et al. (2021)
Near-infrared spectroscopy (NIRS)	Contactless, non-destructive, both physical and chemical modifications, affordable, environmentally benign, quick, and suitable for online use	Low spatial resolution or absence of spatial information	Cozzolino et al. (2019)

Computer vision	Contactless, non-destructive, measures both physical and chemical variances as well as defects, and is applicable to various types of food	No measurement of internal features	Mohammed et al. (2021)
Hyperspectral imaging	Contactless, non-destructive, physical and chemical analysis, defect measurement, extensive spectral data, applicable to various types of food	High cost and system complexity	Liu et al. (2020)
Electric impedance	Internal characteristic measurement, changes in both physical and chemical properties	Contact measurement, a lack of spatial data or inadequate spatial resolution, and the measurement of external properties	Mizuno et al. (2015)

Radio frequency (RF) and microwave	Wide frequency spectrum, rapid, sensitive, direct internal characteristic measurement, non-destructive, both physical and chemical changes	Low spatial resolution, no spatial information, difficult calibration, and no assessment of external characteristics	Huang et al. (2019)
Gas sensor array	Contactless, non-destructive, affordable measurement of spoilage, gas, and toxins	Chemical property measurement only	González-Casado et al. (2015)
pH sensor	Simple system, chemical properties measurement	Contact measurement, local test, chemical property measurement only	Rohani et al. (2020)

2.5 Antenna

Knowing the characteristics of the antenna is crucial before rebuilding the system. An antenna is a passive device that facilitates the transmission and reception of electromagnetic waves, converting directed waves into free-space waves, and vice versa. By converting guided wave energy to free space wave energy or vice versa, this device may efficiently radiate electromagnetic waves in the air for wireless communication purposes. Only the frequency range set by the user can be used by the antenna to receive or send electromagnetic radiation.

The transmission line may be a waveguide or coaxial line that can convey the electromagnetic wave from the source to the antenna or from the antenna to the receiving antenna in order to transport the electromagnetic energy. As a result, the antenna is also known as a system that can radiate and capture electromagnetic energy by fusing the atmosphere to the transmission lines first, then the other way around. The electrical energy is transported by the antenna through the transmission line and transformed into an electromagnetic wave. The antenna at the receiving end turns the electromagnetic waves back into electrical energy and sends it through the transmission line.

Apparently, the size of the antenna is inversely proportional to the frequency. This can be characterized by relationship between wavelength, λ and frequency, f given as:

$$\lambda = \frac{c}{f} \quad \text{Equation 2.1}$$

where, c is the speed of light. However, the large antenna only capable to radiate the low frequency of the electromagnetic wave. If the smaller the size or wavelength of the antenna,

the higher the efficiency to radiate the high frequency of the electromagnetic wave. When designing the antenna, it is important to know the parameter involve such as bandwidth.

2.5.1 Antenna Parameters

In designing the antenna, few parameters need to be considered such as bandwidth, directivity, gain, input impedance, radiation efficiency, radiation pattern, return loss and Voltage Standing Wave Ratio (VSWR).

2.5.1.1 Bandwidth

Bandwidth defines as the frequencies range which the antennas can operate properly in order to receive or radiate the electromagnetic energy. Since the bandwidth of the antenna is measured in hertz, an antenna may operate in the range of 100 MHz to 450 MHz with Standing Wave Ratio (SWR) less than 2:1. Besides that, the bandwidth also can be expressed in terms of the center frequency percentage of the band.

$$Bandwidth = \frac{f_H - f_L}{f_c} \times 100\% \quad \text{Equation 2.2}$$

where, f_c is the center frequency in the band, f_H is the highest frequency in the band and f_L is the lowest frequency in the band. The equation shows that the bandwidth is constantly relative to the frequency and expressed in percentage. If the bandwidth is expressed in the unit of frequency, the bandwidth different depending on the centerfrequency. Thus, the center frequency in the band becomes one of the important parameters used to decide upon the antenna.

2.5.1.2 Directivity

Directivity described as the maximum radiation intensity from the antenna to the average radiation intensity ratio in the given direction. There is possibility to use the antenna directivity to focus on the radiation beam in the desired direction. This also shows that the antenna can concentrate the energy in a certain direction during transmitting or receiving the energy.

2.5.1.3 Gain

The gain of an antenna is the energy amount that radiated in the given direction in the same direction that the isotropic antenna would radiate. Gain also can be described as the performance of antenna to focus the energy via the direction that provide a better radiation image. Besides that, there is a relationship between directivity and gain. Since the gain, G is related to the directivity, this parameter can be expressed as;

$$G = \eta D \quad \text{Equation 2.3}$$

where, η is the efficiency of the antenna and D is the directivity of the antenna.

2.5.1.4 Input Impedance

The input impedance is the impedance that shows the voltage to current ratio at a terminals pair in the antenna. To match the input impedance of the transmission line and the antenna, the 50Ω impedance must be terminated in the antenna to achieve maximum power transfer. However, the reduction on overall system efficiency occurred if the input impedance of the transmission line does not match with the antenna. This is due to the reflected wave that transferred back to the energy source after the wave generated at the antenna terminal. This efficiency loss has occurred when the antenna is used to receive or transmit energy.

2.5.1.5 Radiation Efficiency

The radiation efficiency of the antenna also can be known as the antenna efficiency. This efficiency is used to calculate the ratio of radiated power to the total input power accepted by the antenna. Since the radiation efficiency is related to the resistance, the radiation efficiency which denoted as η can be expressed as;

$$\eta = \frac{R_r}{R_r + R_i} \times 100 \quad \text{Equation 2.4}$$

where, R_r is the radiation resistance and R_i are the loss resistance. From Equation 2.4, the radiation resistance influences the antenna radiation efficiency. The greater the radiation resistance, the greater the antenna radiation efficiency. However, from the impedance matching theory, the radiation resistance must match with the input impedance. If the input impedance does not match, part of the signal from the source reflected back and degrade the performance of the system.

2.5.1.6 Radiation Pattern

The radiation pattern is the variation of the power radiated by an antenna to create the graphical representation of the radiation effect from the antenna. This power is radiated or received by the transmitting antenna or the receiving antenna, respectively. The radiation pattern shown in the far field region and represented as the directional coordinates function. The far field is also known as the radiated field plot that considers as the angle function at the specified distance.

The excellent way to illustrate the radiation pattern is through the 3D pattern which can show the radiated field distribution the angle ϕ and θ in space. However, the difficulty occurs when measuring the 3D pattern in practice due to time-consuming. The H plane and E plane, which are the two main planes in the radiation pattern, are what need to be most concerned

about. While the magnetic field is applied to the radiation pattern on the H plane, the electric field is applied to the radiation pattern on the E plane, as shown in Figure 2.2.

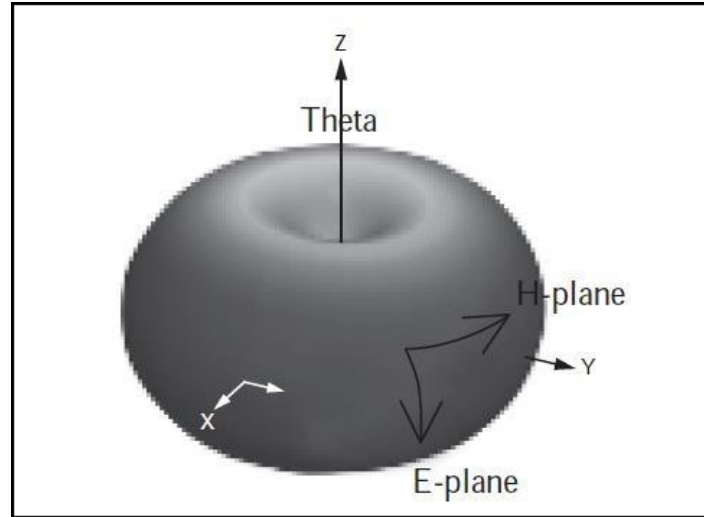


Figure 2.2: The 3D Radiation Pattern with E Plane and H Plane (Midsala et al., 2017)

2.5.1.7 Polarization

The electromagnetic wave being radiated by the transmission system to the direction in space of the E-field part is referred to as the antenna polarization in a certain direction. When the direction is not given, it is assumed that the polarization is polarized in the direction of highest gain. The pattern in different division may have unique polarizations as the polarization may differ from amidst of the antenna. Usually, the low frequency antennas are polarized in vertical direction due to the physical construction technique and reflected wave while the high frequency antennas are mostly polarized in horizontal direction.

The electric field of light that is restricted to a single plane along its propagation direction is known as linear polarization. When the electric field vectors satisfy the requirements that the electric field of light is only polarized in one section or the two orthogonal straight segments are 180^0 or multiples of it, the linear polarization is achieved.

Two perpendicular linear elements with comparable amplitudes and a $\pi/2$ phase difference make up the circular polarization, which is defined as the electric field of light. Due to the rotation direction's influence on the propagation direction, the resulting electric field rotates cyclically. This resulting electric field known as left or right hand circularly polarized light.

In general, all emitted waves have two components that are in the same plane and are polarized elliptically. The two types of elliptical polarization that are most frequently encountered are circular, in which the two E-field components are equal in amplitude and oriented at 90° to one another, and linear, in which the wave has just one E field component.

2.5.1.8 Return Loss

In practical, the load in the circuit usually suffers from mismatch condition between the available source power and power delivered to the transmission line which also the whole power is not delivered to the load (Octavianti & Jaswir, 2017). This mismatch condition causes the return of the power that known as Return Loss (RL) which is the ratio of reflected power, $P_r = P^-$, to incident power, $P_i = P^+$, or can be expressed as;

$$RL = -10 \log \left(\frac{P_r}{P_i} \right) = -10 \log |\Gamma_{in}|^2 - 20 \log |\Gamma_{in}| \quad \text{Equation 2.5}$$

Where Γ_{in} is the input reflection coefficient. This equation applied when matching between the antenna and the transmitter. When $\Gamma_{in} = 0$ and $RL = \infty$, there is no power that can reflect back. Meanwhile, all incident power able to reflect back if $\Gamma_{in} = 1$ and $RL = 0\text{dB}$. Other than that, the impedance matching shows the good performance when the indication of RL is lower than -10dB .

2.5.1.9 Voltage Standing Wave Ratio (VSWR)

VSWR also refer as Standing Wave Ratio (SWR). This parameter is the measure of how good the quality of the antenna is impedance matched with the transmission line. VSWR is the measurement for the amplitude of the ratio of the maximum standing wave to the minimum standing wave which can be expressed as;

$$VSWR = \frac{1+|\Gamma|}{1-|\Gamma|} \quad \text{Equation 2.6}$$

where, Γ is the reflection coefficient. The VSWR can only show the measurement between 1 and ∞ . To achieve the good quality of the impedance matching, the VSWR must be smaller so that more power able to deliver to the antenna when the antenna is matched with the transmission line.

2.5.2 Types of Antennas

Antenna can be divided into few categories such as end fires antenna, which includes helices antenna or polyrods antenna, loops antenna, dipoles antennas, stubs (conical), slots or aperture. In this section, information on types of antenna explained further.

2.5.2.1 Dipole Antenna

An antenna is called as a dipole antenna when energy is radiated from any bent wire. The input impedance reactance is a consequence of the dipole's radius and length. As the radius becomes smaller, the amplitude reactance become greater. Due to this, the radius and length of dipole must be interpreted.

For bilateral symmetry, the dipole antenna is separated into two comparable conducting elements, such as rods or metal wires. The operating current of the transmitter is applied, or the output signal to the receiver is delivered between the two sections of the antenna.

2.6.2.2 Array Antenna

An array antenna, often called a phased antenna, consists of two or more antennas working together as one to boost transmission and reception capabilities. The radiating structure of the antenna is composed of individual elements and radiators. Each of these radiators has an induction field. Due to their near proximity, the elements are affected by the induction field of their adjacent.

The radiation pattern is the single vector sum. The array antenna improves overall gain by providing diversity reception. However, there are some disadvantages of array antenna because of its volume, raised expense, and complexity in antenna architecture. In terms of antenna array benefits, it has a compact design, a high scanning gain, and a broad coverage area.

2.5.2.2 Microstrip Patch Antenna

Microstrip patch antenna consists of a radiating patch above the dielectric substrate on one side and a ground plane at another side. The patch and the ground plane normally made by high conducting material such as copper. The load particularly connects to a microstrip which used to be the linkage between the radiating patch and the ground plane.

Above the ground plane, there is the substrate and the patch is placed on top of the substrate. The relative permittivity for the design of microstrip patch antenna usually larger than or equal to 2.2 and less than or equal to 12. The length of the patch of microstrip patch antenna normally from 0.003λ to 0.05λ .

Microstrip patch antenna radiates due to the fringing field formed between the patch and ground plane. From Figure 2.3, the positive charge distribution appears at a certain point of the patch bottom and the negative charge distribution appear at the ground plane when the

feed excites the patch. Between these two charges, the attractive force is created to hold them on the bottom surface of the patch and top surface of the ground. At the same time, the repulsive charges push some of the charges towards the edge. These charges form the fringing effects and radiation is created.

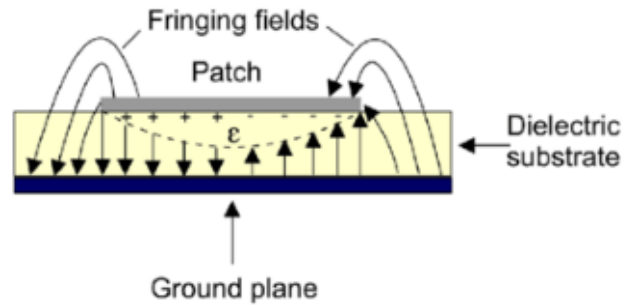


Figure 2.3: The side view of the geometry of a microstrip patch antenna and its radiation mechanism (Chavali & Nikolova, 2019)

Since the substrate gives the separation between the patch and the ground plane, the type of substrate chosen plays the crucial role to determine the antenna dimension. Thus, the substrate with the low dielectric constant can provide the larger bandwidth and better efficiency is the best choice to perform the microstrip patch antenna. Normally, the FR-4 substrate is chosen to design a microstrip patch antenna due to its high relative permittivity, $\epsilon_r = 4.4$ that can form the greater dimension of the patch antenna. Commonly, the patch is in rectangular, circular and square shape due to ease of fabrication. Figure 2.4 show the different common shape of the patch.

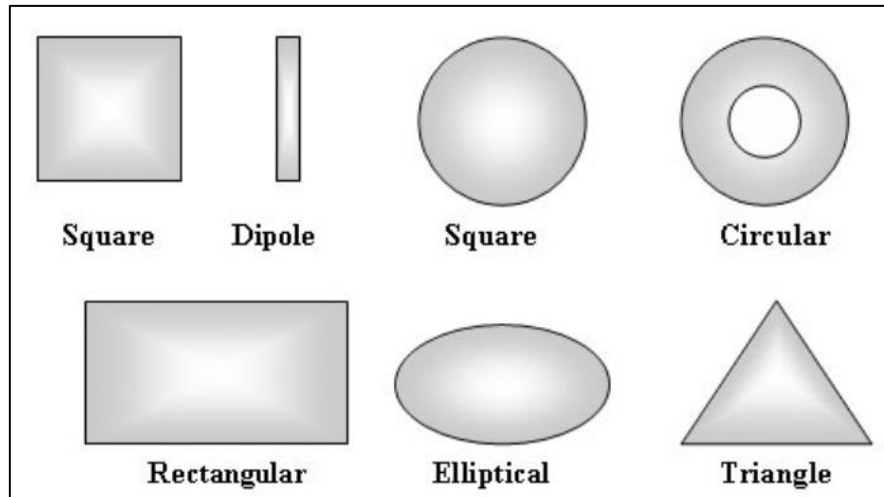


Figure 2.4: Common Shapes of Patch (Abdullah-Al-Mamun, Datto, & Rahman, 2017)

2.5.3 Microbiological Test Technique

Both domesticated animals and wild animals have the salmonella bacterium. They are common in animals raised for food, including chicken, pigs, and cattle. Salmonella can move up the food chain from animal feed to main production to homes, restaurants, and other places that serve food.

Salmonella can be highly hardy, are not destroyed by freezing, and can even live in foods that are acidic. Salmonella is a possible hazard in most meals, especially in dry and semi-dry products (such as milk powder, spices, etc.), due to its great resistance to drying and extremely high heat resistance once dried.

This implies that contamination might be challenging to get rid of if it exists. For instance, rich foods can shield cells from very intense heat treatments, rendering pasteurization useless. Microbiological testing and techniques are methods used to analyse and study of the microorganism such as bacteria and microscopic fungi. In this sub-chapter, three types of

microbiological test technique that has been frequently used are discussed which includes direct microscopic count, spread plate technique and streak plate technique.

2.5.3.1 Direct Microscopic Count

For direct microscopic counts, a particular slide called the Petroff-Hausser counting chamber is required. An aliquot of a suspension of eukaryotic cells is counted in this chamber, and the total number of cells is numerically calculated.

The Petroff-Hausser counting chamber is a thick glass microscope slide with a 0.02 mm (1/50 mm) deep chamber in the center. Upgraded Neubauer rulings (1/400 square mm) and an engraved grid are present in the chamber. The rulings concern 9mm². The boundary lines (Neubauer rules) are the centers of the groups of three.

The triple lines that divide each group of 16 tiny squares in the middle square millimetre act as the boundaries. Volume above a millimetre square is 0.02 mm³ (cubic mm), or 0.02 mm below the ruled surface and 0.02 mm above the cover glass.

This millimetre square counts each cell. The cells counted are determined as in Equation 2.7, where the cell count for 1 mL is calculated using a factor of 50,000: 1 mL is equal to 1000 mm³ or (50 times the 0.02 mm chamber depth) * 1000 (Tandukar, 2021).

$$\text{Number of cells per mm} = \text{number of cells counted} * \text{dilution} * 50,000 \quad \text{Equation 2.7}$$

2.5.3.2 Spread Plate Technique

The technique of spreading plates has become one of the most frequently used methods for culture in microbiology labs due to its convenience of application and simplicity (Devika, 2019). This technique can be used to treat aerobic or facultatively aerobic microorganisms. The sample must be in liquid or suspension for it to work, yet it is a rapid, inexpensive, and efficient

method. The spread plate method, a microbiological laboratory procedure for isolating and counting the live bacteria contained in a liquid sample, involves spreading a certain volume of the sample over the suitable solidified culture media.

Successful spread plates produce distinct colonies that are distributed equally throughout the surface of the culture material following incubation. Using this technique, all the colonies per millilitre (CFU/mL) of viable bacteria present in the sample are isolated and counted. The obsolete culture is also produced in large quantities using this technique. Every culturable fungus and bacteria is compatible with it.

The sample for the spread plate method must be liquid or in suspension. Before plating, the samples are serially diluted. The sample must be diluted to have a microbiological load between 20 and 300 CFU/mL if the purpose is to count CFU/mL (the recommended colony counting range is 20 to 200, although other people say it should be 30 to 300, and on average it is accepted as 25 to 250). This can be achieved by conducting a pilot test or by utilizing multiple diluted samples. The microbial load must first be emulsified and then serially diluted to bring it under the permitted limit if the sample is solid or semisolid.

0.1 to 0.2 mL of the sample is pipetted over the center and distributed evenly over the surface of the solidified agar medium. Colonies are counted after the plates have been incubated for the recommended length of time. If the colonies cannot be counted, are fused, have more than 300 CFU/mL, or have less than 20 CFU/mL, it is advisable to repeat the operation for the best count.

2.5.3.3 Streak Plate Technique

The streaking plate method, a microbiological laboratory procedure, can be applied to distinguish a well-isolated bacterial colony from a mixed population. Although yeasts can also

be isolated using this method, bacterial pure cultures are frequently obtained using it. Microbiology makes use of one of the most common aseptic techniques for isolating and cultivating microorganisms. In microbiology, a mechanical isolation technique known as the "streaking method" is used.

This technique results in well-isolated colonies in the final streaks since a small number of bacteria have been added at the end. The microbial load decreases over time as streaking advances over the surface of the agar medium. The bacteria were therefore mechanically isolated from a mixed population of either the same species or different species using this method. After inoculation, the terminal streaks of a specimen with a single species showed the same types of colonies; nevertheless, a specimen with numerous species might have shown distinct kinds of colonies.

2.5.4 Summary

This chapter presents the important of the microstrip antenna with the parameters that applied in the next chapter. The literature reviews also consist of the research work done and reading progress which are close related to this project. The antenna theory with its characteristics and parameters which must be taken into consideration before the antenna design described in detail. Besides that, there are also various feeding techniques have been explained in this chapter.

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter provides a detailed discussion of the research methodology. The first sub-chapter includes the research stages and a flowchart that illustrates the processes undertaken to achieve the objectives outlined in Chapter 1. Additionally, this chapter covers the antenna design, detailing all relevant design parameters such as scattering parameters, phase difference, impedance, and the dimensions of the transmission line and ground slot line. The chapter also outlines the fabrication process of the antenna and the preparation of the samples.

3.2 Stages of Methodology

This research project is divided into four main stages to complete the objectives stated in Chapter 1. As depicted in Figure 3.1, the stages include; development of a low-cost microstrip patch antenna as resonator, sample preparation for seafood product, analysis of changes in dielectric properties and investigation on the relationship between dielectric properties and resonant frequency.

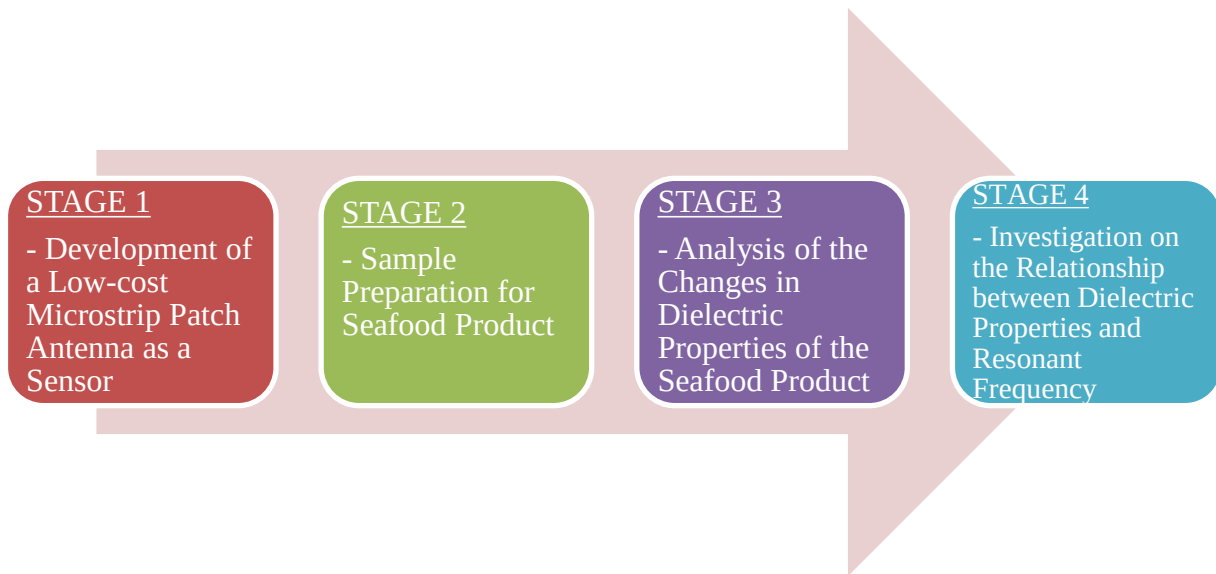


Figure 3.1: Stages of methodology in this project

In stage 1, the development of a low-cost Minkowski Fractal Antenna designed as a sensor at operating frequency for ISM band 2.45 GHz, which is license-free and widely used for various applications. This allows for easy integration into existing technologies. At this frequency, microstrip patch antennas can achieve a good balance between gain, bandwidth, and radiation efficiency. The performance characteristics at 2.45 GHz are often well-suited due to extensive research and development have been conducted at this frequency, leading to well-established design methodologies and optimization techniques, making it easier to achieve desired performance levels.

The simulation results for the performance of the Minkowski Fractal Antenna with iterations must meet the design specifications before fabrication can occur. This step ensures that the Minkowski Fractal Antenna can accurately measure the dielectric properties and resonant frequency of seafood products. Once these criteria are met, the Minkowski Fractal Antenna fabricated. Following fabrication, the antenna undergo validation using a Vector

Network Analyzer (VNA) to confirm its suitability as a resonator sensor for the research project and compare the performance of the iterations. After successful validation, the antenna utilized as a resonator, testing various solutions (including those with sugar and salt) as samples before progressing to Stage 2. At the end of this stage, it is expected to achieve both objective (i) and objective (ii).

In Stage 2, seafood products specifically prawn and fish sourced from various suppliers, including wet markets, mini markets, and hypermarkets in Kuching, Sarawak. Several parameters considered to select the appropriate seafood products, such as the types of prawns and fish to be examined. This careful selection is essential to ensure the accuracy of the data obtained later. The selected seafood divided into several portions. Figure 3.2 illustrates the processes involved in Stage 2.



Figure 3.2: Process in Stage 2

Once the sample has been prepared in Stage 2, the analysis on the changes of the dielectric properties done by using the fabricated Minkowski Fractal Antenna that has been developed in

Stage 1. The Minkowski Fractal Antenna can determine the different amount of dielectric properties in the samples as validation using VNA and solution sample has been made. Dielectric properties are described by the complex dielectric permittivity, ϵ^* of a given sample, expressed in Equation 3.1.

After the samples have been prepared in Stage 2, the analysis of changes in dielectric properties conducted using the fabricated Minkowski Fractal Antenna developed in Stage 1. This antenna is capable of measuring varying dielectric properties in the samples, with validation performed using a Vector Network Analyzer (VNA). The dielectric properties are characterized by the complex dielectric permittivity, ϵ^* of the given sample, as expressed in Equation 3.1

$$\epsilon^* = \epsilon' - j\epsilon'' \quad \text{Equation 3.1}$$

where:

ϵ^* : Complex permittivity is the complex permittivity

ϵ' : Real part of the permittivity, representing the material's ability to store electrical energy

$j\epsilon''$: Imaginary part of the permittivity, representing the material's loss factor

The different amount of unknown solution affects the level of dielectric permittivity (ϵ_r) in the sample based on the equation stated in Equation 3.2 and Equation 3.3.

$$f_o = \frac{v_p}{2l_{eff}} \quad \text{Equation 3.2}$$

$$v_p = \frac{c}{\sqrt{\epsilon_r}} \quad \text{Equation 3.3}$$

As shown in Equation 3.2, variations in dielectric permittivity directly influence the resonant frequency (f_0). Consequently, the data can be analyzed using the detected resonant frequency of the Minkowski Fractal Antenna. During this process, it is essential to minimize losses in the coaxial cable to reduce potential data discrepancies. Additionally, the Vector Network Analyzer (VNA) must be calibrated each time a different sample is analyzed.

In the final stage, Stage 4, the data variations collected from Stages 2 and 3 analyzed and profiled. All experimental data and analyses plotted using SigmaPlot software to ensure clarity when making comparisons. Once the graphs are completed, further investigation on the relation between dielectric properties and resonant frequency under the influence of non-pure solution and microorganism/chloramphenicol of the seafood product can be thoroughly investigated, leading to a comprehensive discussion of the findings. This stage culminates in a conclusion, and it is anticipated that objective (iii) achieved, marking the completion of the research project.

3.3 Overview of the Flow Chart

More detail on methodology explained in this sub-chapter where each step taken and the overview of the research flow is shown in the form of the flow chart. To complete this research, various process was taken as presented in the flow chart presented in Figure 3.3.

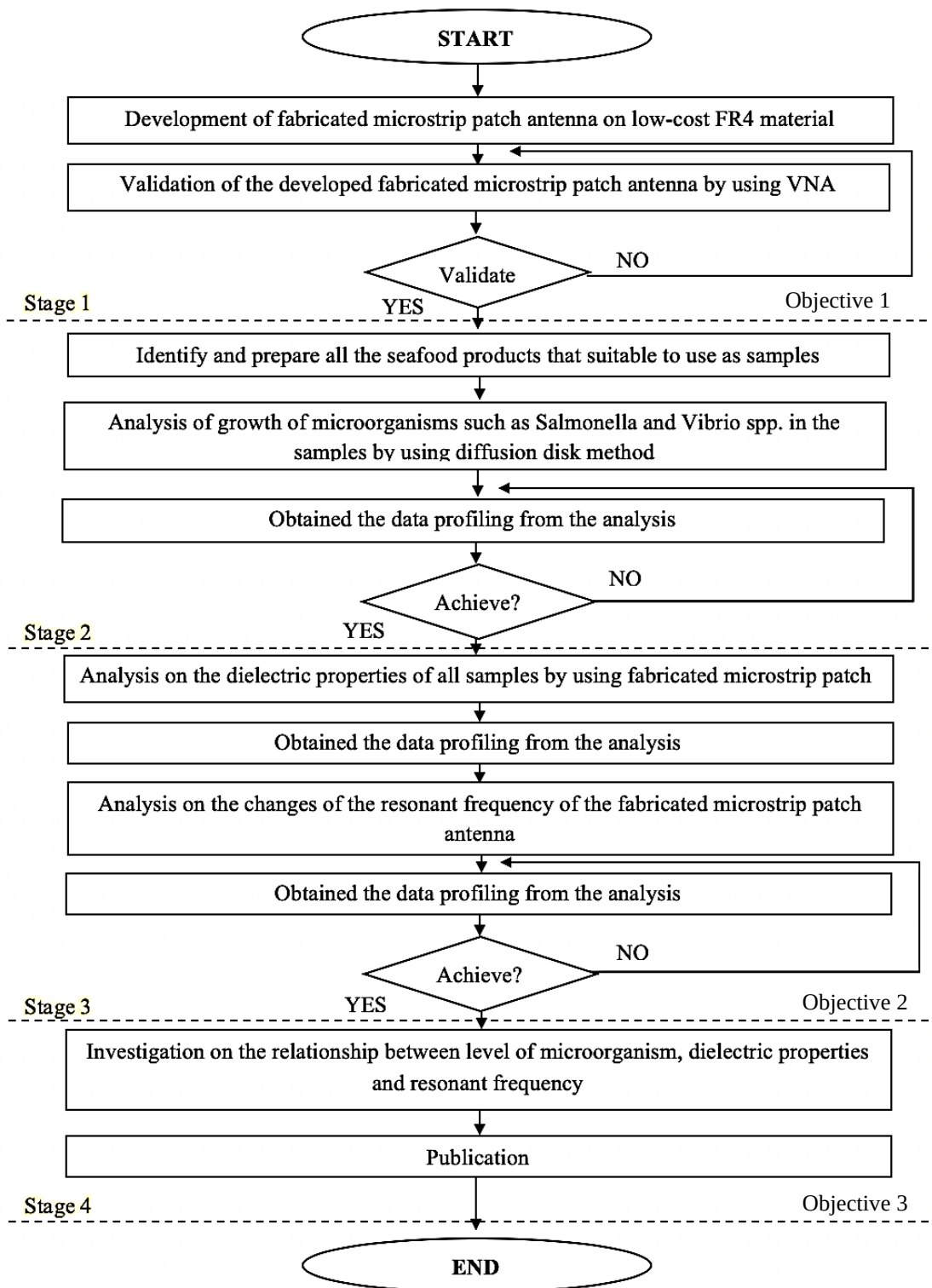


Figure 3.3: Flow chart

3.4 Antenna Component Characterizations

This project was characterized to find a low-cost novel dielectric resonator antenna design. Available dielectric resonator antennas were first used to cover the basic MPA characteristics and performance.

3.4.1 Substrate Component Selection

In designing a dielectric resonator antenna, the choice of dielectric resonator is crucial for optimizing antenna performance. This project explored various types of dielectric resonators, differing in shape and dielectric constant. In the implementation of the Minkowski Fractal Antenna using an existing dielectric resonator, characterizing the resonator is essential for predicting performance and selecting the appropriate feed mechanism. Leung et al. (2017) offer a general equation for calculating the resonance frequency for the three basic shapes: rectangular, cylindrical, and semi-spherical.

For the proposed square Minkowski Fractal Antenna, used Rogers RO4003C substrate, which has a dielectric constant of 3.38 and a thickness of 0.508mm. Roger RO4003C is chosen due to high dielectric constant, with a dielectric constant of 3.38, which allows for smaller antenna designs while maintaining effective performance. It has a low loss tangent, which minimizes signal losses, leading to higher efficiency and improved gain. Compared to other high-frequency substrates, thickness of 0.508 mm is chosen allows for a more compact antenna design without compromising performance. Substrates with a thickness of 0.508 mm have a low dielectric constant (around 2.2) and low loss tangent (0.0009). These properties help in maintaining high efficiency and low signal loss, which are crucial for high-frequency applications like 5G. The dielectric properties of RO4003C are optimized for many RF applications, helping to minimize losses while maintaining effective resonance characteristics.

This thickness also compatible with standard fabrication techniques, ensuring ease of manufacturing and consistency in production. RO4003C is relatively inexpensive, making it a popular choice for many applications. Thus, it is vital to carefully consider the fundamental parameters of the square Miknowski Fractal Antenna during the design process.

Copper has been selected as the conductive material for the patch and ground layer in this study. Because it is the best electrical conductor, copper is frequently used in high, medium, and low voltage power networks. Apart from that, copper conductivity serves as the benchmark for comparison with other conductors.

Since copper has twice the conductivity of aluminum, aluminum wires are being substituted. In the majority of cables used for power and communications, copper wire has long been the favored conductor material. It can be easily drawn down to close-tolerance diameters because to its excellent conductivity and ductility, and it can be easily soldered to provide affordable, long-lasting connections.

Due to being twice as conductive as aluminum and six times more conductive than steel, copper is an ideal choice for the base antenna material. Even though the metal is pliable and soft, it is nevertheless relatively rigid. Thinner wire can be utilized since stainless steel has a higher tensile strength. Because of this, steel is a best material for mobile whip antennas, where flexibility is essential. As electrical efficiency rises, the amount of RF energy that enters and leaves the antenna increases. As a result, the energy won't become trapped and produce heat.

3.5 Antenna Design

Before the design process, the specification of the antenna needs to be known and were chosen carefully to obtain the best outcome for this project. Table 3.1 shows the design specifications of the microstrip patch antenna.

Table 3.1: Design specifications of microstrip patch antenna

Specifications	Value
Centre Frequency	2.45 GHz
Substrate	Rogers R04003C
Dielectric Constant	3.38
Thickness	0.508mm
Ground and Patch Conductor Coating	Copper
Return Loss (dB)	Less than -10dB

Based from Table 3.1, the centre frequency of the chosen design is 2.45GHz where it is an ISM band for Malaysia. Meanwhile, Rogers RO4003C is chosen as the substrate due to its low return loss and it provides tight control on the dielectric constant. Return loss is defined as loss of power in the signal that returned or reflected. Therefore, the value obtained which is lower than -10 dB means that the reflected wave is 10 dB lower than the incident wave.

3.5.1 Initial Design Study

The proposed rectangular microstrip patch antenna has been developed utilizing the substrate Rogers RO4003C with the dielectric constant, ϵ_r of 3.38 and the substrate thickness is 0.508mm. Figure 3.4 depicts the construction of the rectangular microstrip patch antenna where it consists of patch, material and ground plane stack together.

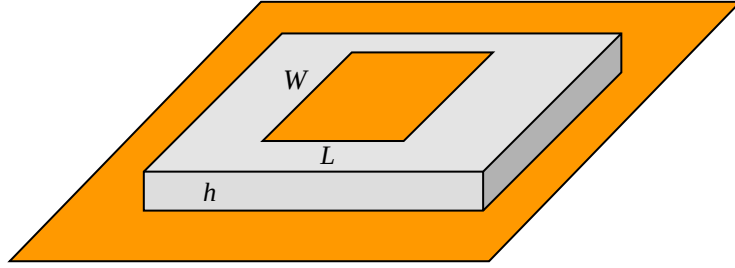


Figure 3.4: Rectangular microstrip patch antenna

The fundamental steps for the development of the rectangular MPA are:

Step 1: A parameter width of the radiating rectangular microstrip patch antenna is determined by using this equation:

$$Wp = \frac{c}{2 * fr \sqrt{\frac{\epsilon_r + 1}{2}}} \quad \text{Equation 3.4}$$

where:

c : Velocity of light, $3 \times 10^8 \text{m/s}$,

ϵ_r : Dielectric constant of the substrate

fr : Resonant frequency of the antenna (Hz)

Step 2: Effective dielectric constant of microstrip patch antenna is calculated as:

$$\epsilon_{eff} = \frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2 \sqrt{1 + \frac{12h}{W}}} \quad \text{Equation 3.5}$$

where:

ϵ_{eff} : Effective dielectric constant

ϵ_r : Dielectric constant of the substrate

h : Substrate thickness (mm)

W : Width of the patch (mm)

Step 3: The effective length can be specified at the resonance frequency:

$$L_{eff} = \frac{c}{2 * f_r \sqrt{\epsilon_{eff}}} \quad \text{Equation 3.6}$$

where:

L_{eff} : Effective length

c : Velocity of light, $3 \times 10^8 \text{m/s}$

ϵ_{eff} : Effective dielectric constant

f_r : Resonant frequency of the antenna (Hz)

Step 4: Extension length of the rectangular microstrip patch antenna is calculated as:

$$\frac{\Delta L}{h} = 0.412 \frac{(\epsilon_{eff} + 0.3) \left(\frac{W}{h} + 0.264 \right)}{(\epsilon_{eff} - 0.258) \left(\frac{W}{h} + 0.8 \right)} \quad \text{Equation 3.7}$$

where:

ΔL : Extension length (mm)

ϵ_{eff} : Effective dielectric constant

h : Substrate thickness (mm)

W : Width of the patch (mm)

Step 5: The actual length of the patch is computed by:

$$Length = Leff - 2\Delta L \quad \text{Equation 3.8}$$

where:

$Leff$: Effective length

ΔL : Extension length (mm)

Step 6: The width of the ground layer can be determined by:

$$Wg = 6h + W \quad \text{Equation 3.9}$$

where:

Wg : Width of ground (mm)

h : Substrate thickness (mm)

W : Width of the patch (mm)

Step 7: The length of ground layer can be determined by:

$$Lg = 6h + L \quad \text{Equation 3.10}$$

where:

Lg : Length of the ground (mm)

h : Substrate thickness (mm)

L : Length of the patch (mm)

3.5.2 Minkowski Fractal Antenna

Minkowski Fractal Antenna is designed based on a square generator structure on previous segment. When iterated from square patch to a smaller scale, the estimation of the initial size is calculated by using the following equation (Ali, 2007):

$$w_1^{(n+1)} = a_1 \times L_N \quad \text{Equation 3.11}$$

$$w_2^{(n+1)} = a_2 \times L_N \quad \text{Equation 3.12}$$

where W_1 is the middle segment width, W_2 is the indentation width, n is the iteration number, a_1 is the W_1 / L_0 ratio and a_2 is the W_2 / L_0 . From the calculation from Equation (3.6-3.12), the value of the square patch length is $L_0 = 108.57\text{mm}$. The indentation ratios, a_1 and a_2 has been set as 0.1 and 0.15 respectively.

Aside from being able to produce multi-band resonances, tuning a_1 and a_2 determine the antenna's most efficient overall size. Lee et al. (2011) stated that a_1 increases proportionally with fractal perimeter length, while the opposite can be said about a_2 . Fractal perimeter length is also found to be decreasing with the reduction of $W_1^{(n+1)}$.

If this parameter is not reduced carefully, it results in an incredibly small dimension, which complicate the fabrication process. Thus, it is important to make sure that a_1 less than a_2 . The higher order fractal elements separate from the primary iterated main structure if you do the opposite. Furthermore, setting $a_1=a_2$ result in elements of different fractal orders overlapping.

3.5.3 Designation and Optimisation of Minkowski Fractal Antenna

The designation of the antennas is simulated with CST Microwave Studio software to ensure that the antennas specification targets had been achieved. Therefore, the structure of the antennas was analyzed to get the optimized result, which has better efficiency that can acts as

an effective signal receiver. Better signal receiver enables the system to have the best performance for FT-NIR level measurement.

The details of Square Patch Antenna design are shown in Figure 3.3(a). The dimensions of square patch are calculated using Equations (3.6-3.10) at the operating frequency 2.45 GHz. The ground plane and radiating patch of the antenna was made up of copper material with thickness of 0.035 mm. The substrate of both antennas was printed on Rogers RO4003C with a thickness of 0.4 mm and dielectric constant of 3.38. Meanwhile, the feeding technique that used for these antennas is 50 Ω coaxial feeding technique.

The MFA antenna design structure had been optimized by changing the radiating patch radius to achieve the targeted frequency band and bandwidth required to cover the NIR spectrum. Finally, the simulation comparison between two antennas were analyzed to validate the performances of the proposed antenna. The final configuration of the proposed square patch and Minkowski fractal antennas based on the parameter that has been optimized by using CST software is shown in Table 3.2 and Figure 3.5(b) to Figure 3.5(e).

Table 3.2: Geometrical Configuration of Minkowski Fractal Antenna

Length of Sides (mm)	Types of Designs				
	Square Patch	First Iteration	Second Iteration	Third Iteration	Fourth Iteration
Patch Width	40.50	38.10	38.86	34.19	33.23
Patch Length	40.50	38.10	38.86	34.19	33.23
Ground Width	50	50	50	50	50
Ground Length	50	50	50	50	50

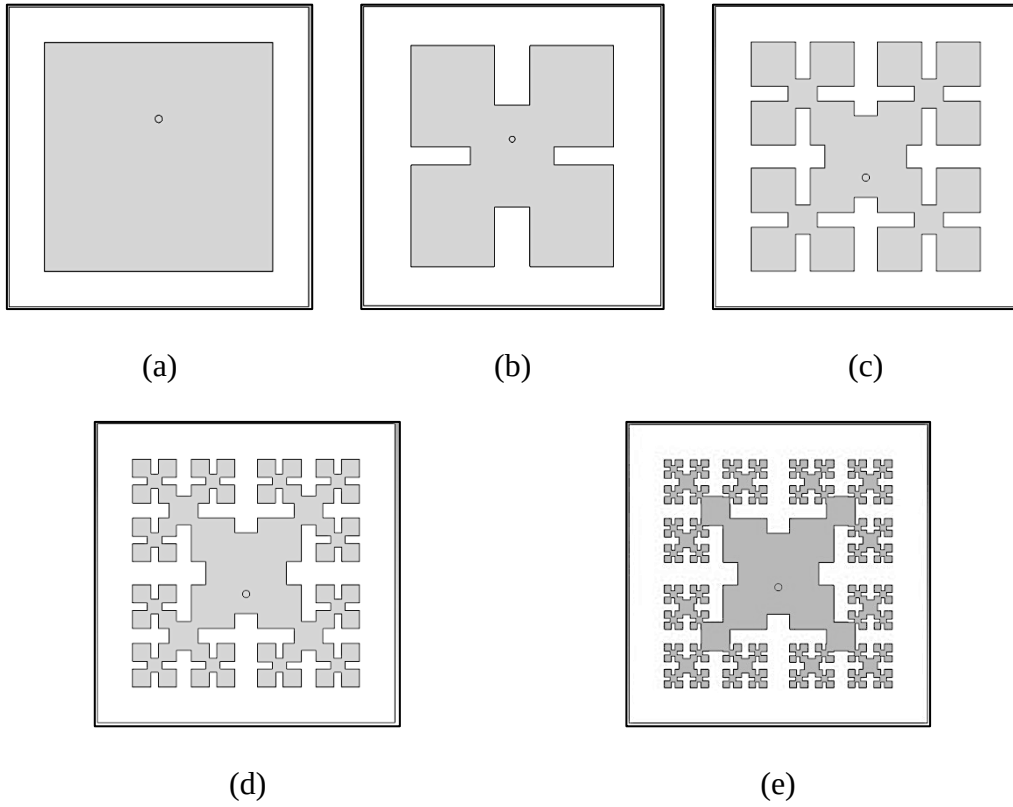


Figure 3.5: Front view of antenna (a) Square Patch, (b) First iteration, (c) Second iteration, (d) Third iteration, (e) Fourth iteration

3.6 Feeding Technique

This sub-chapter explained on the feeding technique for microstrip patch antenna and which used in the research project.

3.6.1 Microstrip Feeding Technique

Figure 3.6 shows the proposed rectangular MPA with microstrip feedline. The width of the feedline, W_f , and the length of the feedline, F_i needs to be calculated by using Equation (3.13) and (3.14) respectively. There is no calculation involved in finding the inset fed, G_{pf} , so consider 1.0 mm as the allowable gap.

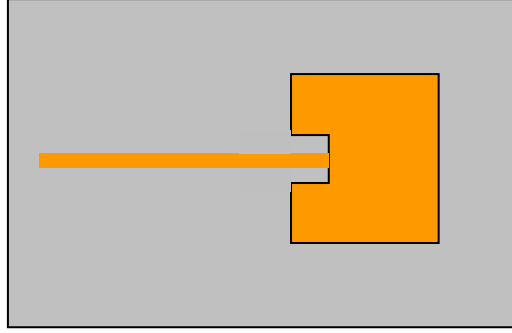


Figure 3.6: Microstrip patch antenna with microstrip feedline

$$Z_c = \frac{120\pi}{\sqrt{\epsilon_{eff} \left[\frac{W_f}{h} + 1.393 + \frac{2}{3} \ln \left(\frac{W_f}{h} + 1.444 \right) \right]}} \quad \text{Equation 3.13}$$

where:

ϵ_{eff} : Effective dielectric constant

h : Substrate thickness (mm)

$$F_i = 10^{-4} \left(\frac{0.001699(\epsilon_r)^7 + 0.13761(\epsilon_r)^6 - 6.1783(\epsilon_r)^5 + 93.187(\epsilon_r)^4}{-682.69(\epsilon_r)^3 + 2561.9(\epsilon_r)^2 - 4043(\epsilon_r) + 6697} \right) \frac{L}{2} \quad \text{Equation 3.14}$$

where:

F_i : Length of feedline

ϵ_r : Dielectric constant of the substrate

The design of MPA with microstrip feedline is shown in Figure 3.7 (a) and (b). Based on both figures, the back view or ground of the conventional microstrip patch consists a fully-occupied material and all the parameter values have been optimized when designing the MPA to fulfil the desired parameters for MPA.

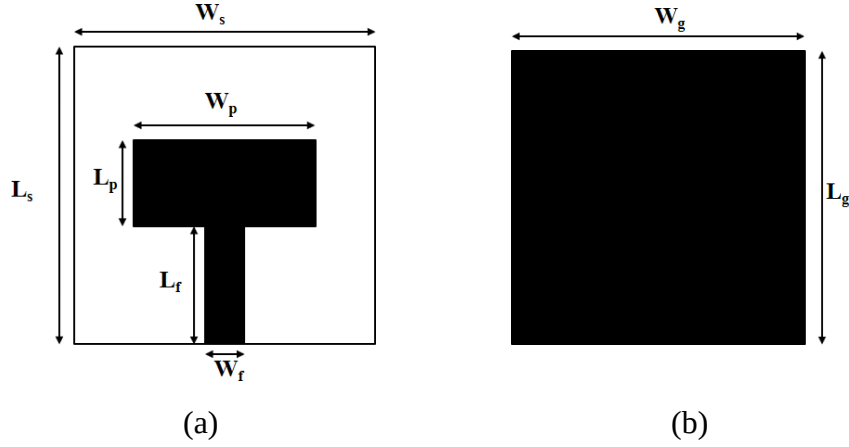


Figure 3.7: Structure for MPA with transmission line (a) Front view (b) Back view

Hence, the optimized values can be summarized in Table 3.3. The calculated W_f and L_f are 1.57 mm and 7 mm, respectively.

Table 3.3: Optimized dimension of microstrip patch antenna with microstrip feedline

Parameters	Values (mm)
Substrate width, W_s	20
Substrate length, L_s	16
Patch width, W_p	15.5
Patch length, L_p	7.56
Ground width, W_g	20
Ground length, L_g	16
Feeder width, W_f	1.57
Feeder Length, L_f	7

All the parameters in Table 3.3 were determined based on theoretical calculations, design equations, and simulation results to ensure that the antenna meets the desired performance criteria, such as resonant frequency, impedance matching, and efficient radiation.

As an example, the substrate width and length were chosen to provide adequate space for the patch and feedline while minimizing surface wave losses. A wider substrate helps to reduce fringing fields and improve radiation efficiency.

Meanwhile, the patch width and length were optimized to resonate at the target frequency where the width will affect the input impedance and bandwidth, while the length is directly related to the resonant frequency of the antenna. The ground plane dimensions were matched to the substrate size to ensure proper electromagnetic field distribution and to avoid unwanted reflections or radiation pattern distortion.

The feeder width was calculated using standard microstrip transmission line equations to achieve a characteristic impedance of approximately 50Ω , ensuring proper impedance matching with the source.

3.6.2 Coaxial Feeding Technique

Figure 3.8 shows the proposed rectangular MPA with coaxial feedline. The distance of the feed points patch length and width to be calculated by using Equation (3.15) and (3.16) respectively.

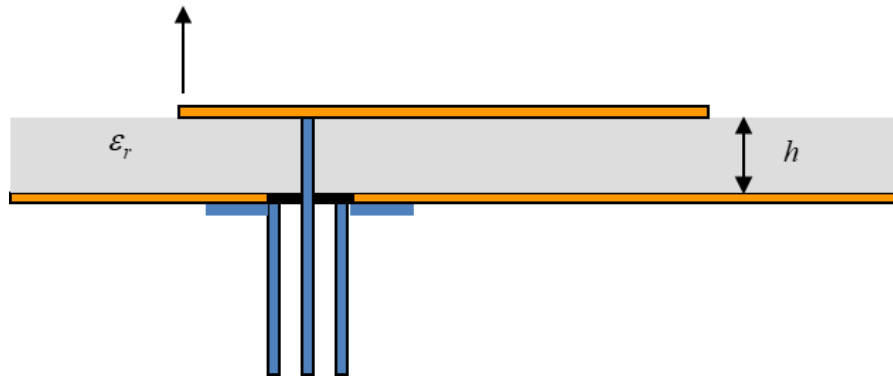


Figure 3.8: Microstrip patch antenna with microstrip feedline

Distance of feed point from L_p (X) :

$$X = \frac{L_p}{2\sqrt{\epsilon_{r_{eff}}}} \quad \text{Equation 3.15}$$

where:

L_p : Length of the patch

ϵ_{eff} : Effective dielectric constant

Distance of feed point from W_p (Y) :

$$Y = \frac{W_p}{3\sqrt{\epsilon_{eff}}} \quad \text{Equation 3.16}$$

where:

W_p : Length of the patch

ϵ_{eff} : Effective dielectric constant

The design of MPA with coaxial feedline is shown in Figure 3.9 (a) and (b).

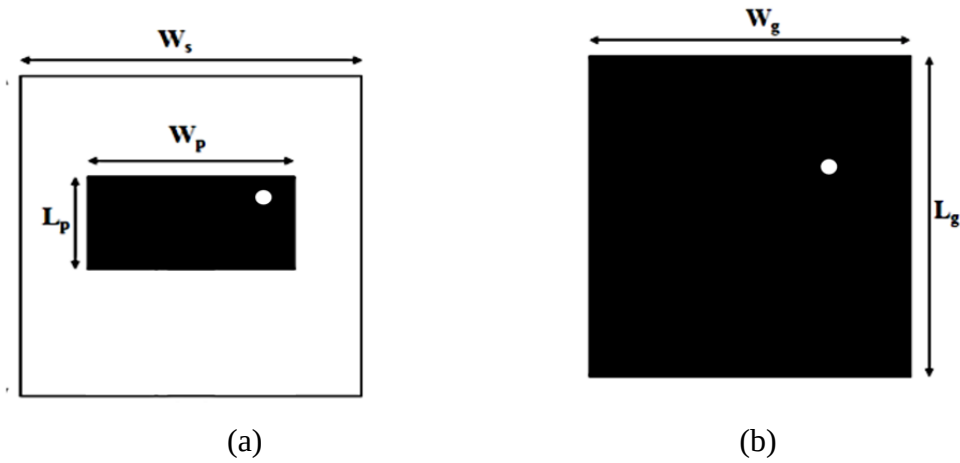


Figure 3.9: Structure for MPA with coaxial feedline (a) Front view (b) Back view

Based on both figures, it can be seen that the coaxial feed located at any place inside the patch so that the input impedance can be matched with the microstrip patch antenna.

The coaxial center conductor in the inner part is extended via the substrate and connected to the radiating patch. Meanwhile, the coaxial connector at the outer part is linked to the ground plane. The feed location is located one-third of the distance from the center of the patch to the side in the coaxial probe. Hence, the optimized values can be summarized in Table 3.4.

Table 3.4: Optimized dimension of microstrip patch antenna with coaxial feedline

Parameters	Values (mm)
Substrate width, W_s	20
Substrate length, L_s	16
Patch width, W_p	15.5
Patch length, L_p	7.56
Ground width, W_g	20
Ground length, L_g	16
Feed location, X_f	9.21
Outer radius of the coax probe, R_o	2.5
Radius of the pin, R_i	0.5

Similar to Table 3.3, all the optimized values for all parameters in Table 3.4 too were determined based on theoretical calculations, design equations, and simulation results to ensure that the antenna meets the desired performance criteria, such as resonant frequency, impedance matching, and efficient radiation.

3.7 CST Microwave Studio

CST Microwave Studio is a Computer-aided Design (CAD) software that specially used for the 3D EM simulation and the antenna design. This software is similar to 3D EM platforms, it can be used to interpret the EM behaviour and the multi-layer structure of the high-frequency designs. CST software is also used to simulate the antenna and give the theoretical results which is comparable to the real antenna. Figure 3.10 shows the interface of CST Microwave Studio.

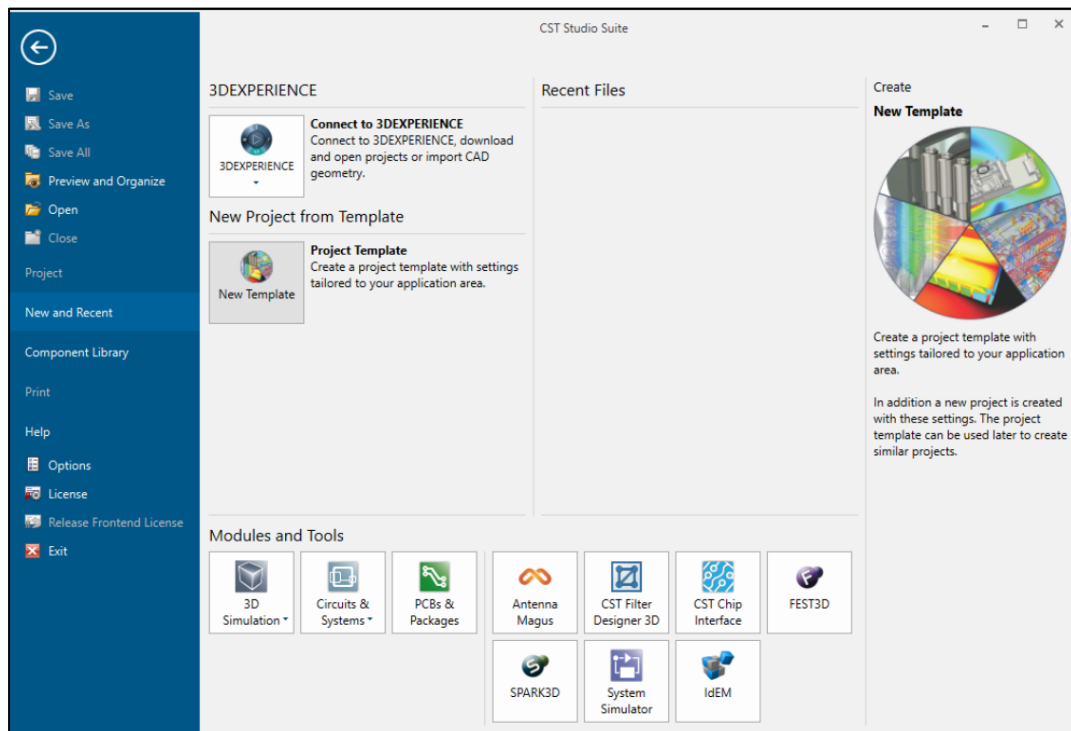


Figure 3.10: Interface of CST Microwave Studio software

3.8 Fabrication Process

This section describes six stages of designing and the fabrication process of microstrip patch antenna as shown in Figure 3.11. The dimensions of designed rectangular microstrip patch antenna are given in the Table 3.2.

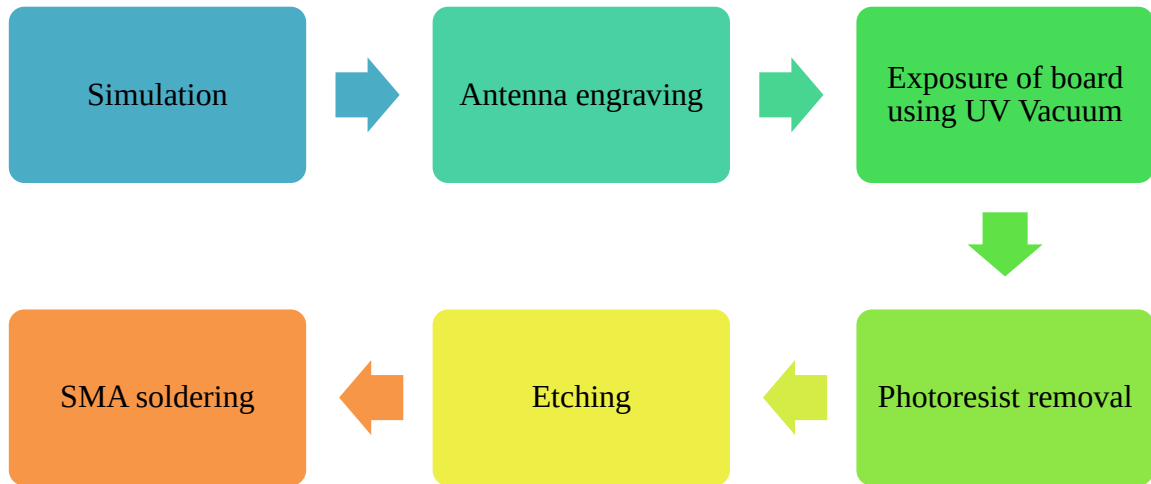


Figure 3.11: Fabrication process of an antenna

As mentioned earlier, the first stage before fabricating the antenna is designing antenna by using CST Microwave Studio. The antenna must be operated with resonant frequency range between 1 GHz to 3 GHz, with a return loss of -10 dB or less. Antennas designed for frequencies in this range can be made compact enough while still maintaining good performance characteristics, such as efficiency and gain.

After designing antenna by using the software, antenna engraving done. The exact dimensions and size of the antenna engraved on the PCB (Rogers RO4003C) by using Proteus Design Suite. Computer Numerical Control (CNC) machine receive the design and engrave the antenna on the Rogers RO4003C, accordingly. The mask is made from a negative print of this

geometry on translucent sheet. Acetone is used to completely clean and dry a 65 mm X 65 mm double-sided copper clad substrate RO4003C. The etched pattern is disrupted by dust or other contaminants on the copper-clad surface, changing the resonance frequency.

After the copper clad substrate has been cleaned and dried, a negative photo-resist film is laminated to it. The photo-resist laminated copper clad substrate is firmly attached to the negative mask that was made in the first phase. UV light is shone on the copper-clad substrate that has been mask and photo-resist laminated. is going to be exposed to UV radiation in a double-sided UV vacuum.

UV light with the right wavelength and photoresist sensitive to this wavelength are required for the photolithographic process. Positive and negative photo-resist materials are available. Negative photoresist hardens, while the exposed area of positive photoresist dissolves in the photo-resist developer. In Figure 3.12, photo-resist material in the form of dried negative photo-resist film is to be laminated to the copper-clad substrate and UV.



Figure 3.12: Photo-lithographic method

As shown in Figure 3.13, the third stage is developing the UV exposed photo-resist laminated copper clad substrate. Unexposed photoresist remains light blue and dissolves in the developer solution, however photoresist that has been exposed to UV radiation hardens and changes color to a dark blue hue. As a developer, sodium carbonate is employed.



Figure 3.13: UV exposed photo-resist

Removal of photoresist is the fourth stage. At this stage, photoresist that exposure to UV light through film positives entirely removed by immersing the board in a tray with positive developer chemical as shown in Figure 3.14. The developer dissolve away any regions that were exposed to the UV light, leaving the desired shape of the microstrip antenna for etching. The board then rinsed with water to remove any excess chemical.



Figure 3.14: Removal of photoresist

The etching process in the fifth stage utilize the etching machine shown in Figure 3.15. The FR-4 board is etched by removing excess copper. A ferric chloride (FeCl_3) solution chemically etches the copper-clad substrate, causing the copper to dissolve except for the areas protected by the firm photoresist.



Figure 3.15: Etching machine

To get rid of any remaining etchant, the etched substrate is rinsed under running water and dried. Use of sodium hydroxide is used to remove the hardened photo-resist. Figure 3.12 previously depicts the rectangular microstrip patch antenna that was photolithographically fabricated. The 50 SMA port is soldered to the transmission line during the final stage.

3.9 Measurement and Analysis Setup

In this sub-chapter the setup for the measurement and analysis stage are explained. All the results from the measurement and analysis explained in Chapter 4.

3.9.1 Detection of Salt and Sugar Analysis

A total of six samples with different concentrations of salt and sugar is prepared to be used in this research. This sample change the original dielectric properties of the pure solution and distort the radiation of the microstrip patch antenna. The salt and sugar are mixed with water to make salt solution and sugar solution, respectively. To reduce any unwanted impurities such as microorganisms, the water boiled until 100°C before being mixed with salt and sugar.

Figure 3.16 shows the process of weighting the salt and sugar before mixing with the boiled water.



Figure 3.16: Preparation during weighting of salt and sugar

Figure 3.17 depicts the measurement process of detection the sugar and salt solution. As seen, the antenna used coaxial cable feeding technique. This to avoid the SMA to be immersed in the solution that can caused to incorrect results.

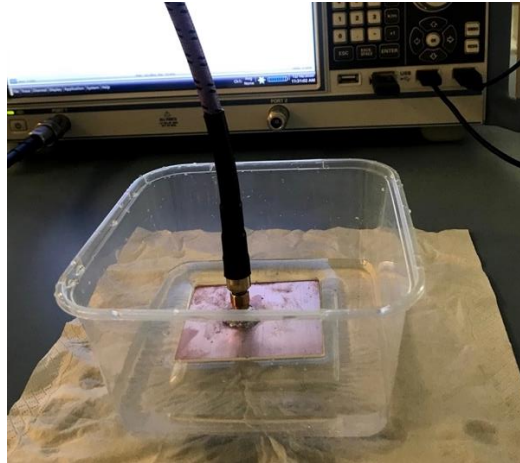


Figure 3.17: Measurement process

3.9.2 Low, Medium and High Concentration of Salt Solution

Five containers denoted as containers A, B, C, D and E for salt solution. Each container has a different weight of table salt in gram (g). For container A, only 50g of salt mixed with boiled water in. Container B, C, D and E has a weight of 100g, 150g, 200g and 250g of salt, respectively. Each number of salt weights indicates a different level of concentration of salt solution. 50 g indicates low concentration, 150g of table salt represent medium concentration and lastly, 250 g signify high concentration.

3.9.3 Low, Medium and High Concentration of Sugar Solution

Another five containers denoted as containers F, G, H, I and J for salt solution. Each container has a different weight of table sugar in gram (g). For container F, only 50g of sugar mixed with boiled water in. Container G, H, I and J has a weight of 100g, 150g, 200g and 250g of sugar, respectively. Each number of sugar weights indicates a different level of concentration

of sugar solution. All solution needs to be prepared after the fabrication process to avoid any unwanted impurities changing the properties of the samples.

3.9.4 Summary for Salt and Sugar Solution

Table 3.5 shows the summary of weight for salt and sugar. Container A and F, B and G, C and H, D and I, E and J have the same weight of 50g, 100g, 150g, 200g and 250g of impurities, respectively.

Table 3.5: Weight of impurities for salt and sugar solution for each container

Impurities	Container	Weight of Impurities (g)
Salt	A	50
Salt	B	100
Salt	C	150
Salt	D	200
Salt	E	250
Sugar	F	50
Sugar	G	100
Sugar	H	150
Sugar	I	200
Sugar	J	250

3.10 Analysis on Yellow Tail Fishes in Different Temperature Condition

In this analysis, three samples of yellow tail fishes with different condition were acquired from a local supermarket. Three yellow tail fishes were selected for weight, 15-25g, with the absence of quality defects. Fish with noticeable hardness or any physical deformity were rejected. The fish were vacuum seal in the package. Then, the samples were split into three different conditions: CO₂ blast freezer at -45°C, room temperature of -20°C and blended solution.

To remove sand and unwanted objects, received fish are weighed and washed in tap water that is around 5°C in temperature. To kill some germs, fish are given a second washing in water that is roughly 5°C and contains active chlorine at 0.2-0.5 ppm for 1 minute. They are then placed for 1-3 minutes at a temperature of around 5°C in a solution of 1% metabisulfite to stop the growth of melanosis (black spots).

In three processing lines, beheaded shrimp, peeled shrimp, and whole shrimp are separated and marked. The beheaded and peeled fish are bathed in plain water for three minutes at about 5°C, while the entire fish receive a second soaking in a solution of 0.25% metabisulfite for one to two minutes. After that, the fish are placed in a polystyrene box for testing in the lab.

3.11 Detection of Chloramphenicol in Shrimp

The samples used to assess the various procedures all underwent the same preparation process in order to be assessed for their ability to count microorganisms. The products were poured into sterile plastic beakers in an amount of 200 mL. Using a sterile loop, one colony from one colony from the petri plates with microorganisms was injected into the liquid collected from the seafood products used as matrices for this project. The mixture was then blended by shaking the plastic beakers. The samples were incubated for three days at 25 °C. Following that, the samples were diluted as shown in Figure 3.18.

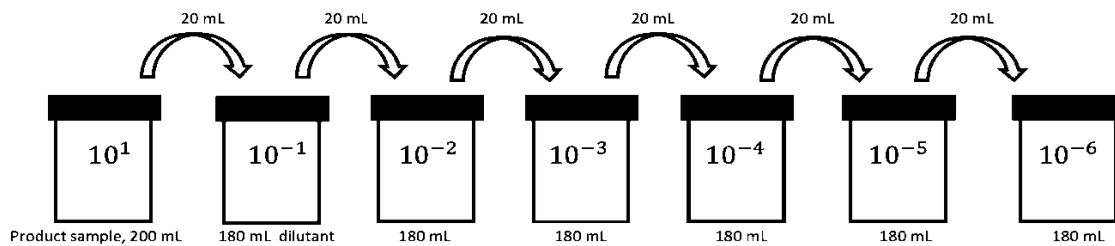


Figure 3.18: Schematic over the dilution of samples

All dilutions were created using sterile 0.9% NaCl solution in the same kind of sterile beaker as the inoculation. The NaCl solution was then put into beakers in an amount of 180 mL. The first beaker received 20 mL of the infected product, which was properly mixed by shaking. This becomes the initial 1/10, or 10^{-1} , dilution of the original sample. Once the required range of dilutions from 10^{-1} to 10^{-6} is attained, the process is repeated by transferring 20 mL from 10^{-1} to the following beaker. Depending on the organism used for the inoculation and the various techniques, the dilutions were then plated on both selective and generic substrates. The whole sample preparation is shown in Figure 3.19.

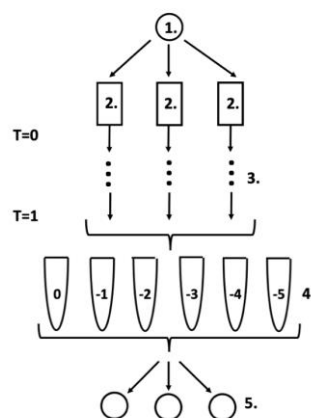


Figure 3.19: Overview over the sample preparation

Chloramphenicol has been identified as an aplastic anemia cause and a potential human carcinogen in animal products, including farmed fish and shrimp. Chloramphenicol use was

prohibited as a result of these health worries. Chloramphenicol is still commonly accessible in developing nations, nonetheless. As a result, a highly sensitive and specific analytical instrument is required to monitor and manage chloramphenicol residues in challenging matrices, such as food products.

A total of five samples with different concentrations chloramphenicol and shrimps prepared to be used in this research. The chloramphenicol is mixed with water to make solution for the shrimps. Five containers denoted as containers C1, C2, C3, C4 and C5. Each container has a different weight of chloramphenicol in milliliters (mL). For container C1, only 50mL of chloramphenicol mixed with water. Container C2, C3, C4 and C5 has a weight of 100mL, 150mL, 200mL, and 250mL of chloramphenicol, respectively as shown in Figure 3.20. Each number of chloramphenicol indicates a different level of concentration. 50mL indicates low concentration, 150mL of chloramphenicol represent medium concentration and lastly, 250mL signify high concentration.



Figure 3.20: Shrimp soaked in a chloramphenicol solution for one hour

3.12 Summary

In this chapter, the methodology of the research and the features of Minkowski Fractal Antenna and the parametric result has been discussed. The method used and the flow chart has been explained briefly in this chapter, the flowchart of the research and the simulation steps have been elaborated in detail. The design specification of antenna has been determined and some important parameters have been calculated based on the formula.

After that, the calculated parameters of the square microstrip patch antenna summarized in table form. The step of designing square microstrip patch antenna and Minkowski Fractal Antenna also explained in detail. Besides that, different feeding technique in the both antennas also elaborated in detail. Measurement and analysis setup for the research project has also been presented in this chapter.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

The design of the patch antenna and the simulation results covered in this chapter. The revised Minkowski fractal antenna design with several iterations then be presented. The bandwidth and phase difference of the antenna are intended to be increased by this upgraded design. The formulas from Chapter 3 were used to initialize the values for each dimension, and the square patch antenna was chosen as the initial design for this research project. To get the optimized performance, parameter sweep and optimization were done in the Computer Simulation Technology (CST) software. The final design antenna is picked to be fabricated after achieving the best performance.

4.2 Rectangular Microstrip Patch Antenna

Based on sub-chapter 3.5.1, a rectangular microstrip patch antenna with initial parameter is designed. This design allows for an easier comparison with Minkowski Fractal Antenna's performance across different configurations and iterations. Referring to Chapter 3, Figure 3.7(a) shows the front view of the rectangular microstrip patch antenna design. As seen in the figure, the length and the width of the antenna is 30 mm. Meanwhile, Figure 3.7(b) shows the back view of the antenna. As observed, in this initial study, microstrip feeding technique is used. Then, once designed, the antenna is fabricated. Thus, the comparison of the simulated antenna and fabricated antenna in terms of dimension is presented in Table 4.1.

Table 4.1: Dimensions comparison of the simulated and fabricated antenna

Parameters	Simulated antenna (mm)	Fabricated antenna (mm)
Patch width, W_p	50.00	40.50
Patch length, L_p	50.00	40.50
Feedline width, W_f	3.00	2.67
Feedline length, F_i	7.7	7.39
Inset fed, G_{pf}	1.0	1.43
Ground width, W_g	50.00	50.00
Ground length, L_g	50.00	50.00

In the width measurement, the patch is reduced from 50.00 mm to 40.50 mm. Simulations antenna often use idealized models that may not account for all physical aspects, such as fringing effects or material inhomogeneities, which can alter the effective patch size. As the width is reduced, the reflection coefficient affected more than the resonant frequency.

The reflection coefficient, which indicates how much of the signal is reflected back rather than transmitted, is increasing. This typically suggests that the antenna is becoming less efficient at matching the desired impedance, leading to more reflected energy. The resonant frequency, which is the frequency at which the antenna is designed to operate most effectively, is shifting to a higher frequency (to the right on a frequency graph). Together, these changes indicate that the actual performance of the antenna differs from what was expected or simulated, which could be due to factors like material properties, fabrication tolerances, or other design discrepancies.

When the measurements from the fabricated antenna are applied to the simulation, it is observed that the reflection coefficient increases and the resonant frequency shifts to a higher value. Both the resonant frequency and the reflection coefficient are affected by reducing the patch length from 50.00 mm to 40.50 mm. A shorter patch results in a lower reflection coefficient, and the resonant frequency shifts to a maximum value on the higher end.

Regarding the dimensions of the ground plane, although the antenna is initially designed as a square with equal sides, post-fabrication, the measurements differ. The width of the ground plane changes from 57.84 mm to 56.17 mm, and the length changes from 57.84 mm to 56.63 mm. During the process of trimming excess material, which explained later, some parts were removed. Fortunately, these changes to the ground plane do not significantly impact the resonant frequency. However, the reflection coefficient decreases by 1.5%.

In the simulation, the line impedance is calculated to be 50.14 Ω . To minimize power loss, the line impedance should be kept below 50 Ω . If the impedance is mismatched or exceeds 50 Ω , the total reflected power or reflection coefficient high. For the fabricated antenna, reducing the feedline width from 3.0 mm to 2.67 mm has resulted in an increase in line impedance, leading to greater power loss. Conversely, changing the feedline length from 7.7 mm to 7.39 mm does not affect the line impedance. Similarly, the inset feed length increases from 1.0 mm to 1.43 mm, although the effect is minimal.

The S_{11} parameter, also known as return loss, represents the mismatch loss of the antenna. Achieving the lowest S_{11} value, ideally below -10 dB, is desirable. A lower S_{11} indicates reduced power loss and enhances the receiving antenna's ability to capture signals within a specific operating frequency range (Lee et al., 2011).

Figure 4.1 and Table 4.2 illustrate the comparison of the resonant frequency and reflection coefficient between the simulated and fabricated antennas using a Vector Network Analyzer (VNA). From Figure 4.2, the reflection coefficient for the simulated rectangular microstrip patch antenna, obtained from CST Microwave Studio, is -19.56 dB at 2.51 GHz, while the measured result is -41.39 dB at 2.45 GHz. The measurement improves by 71.63%

compared to the simulation result. The difference in resonant frequency between the two results is 0.06 GHz.

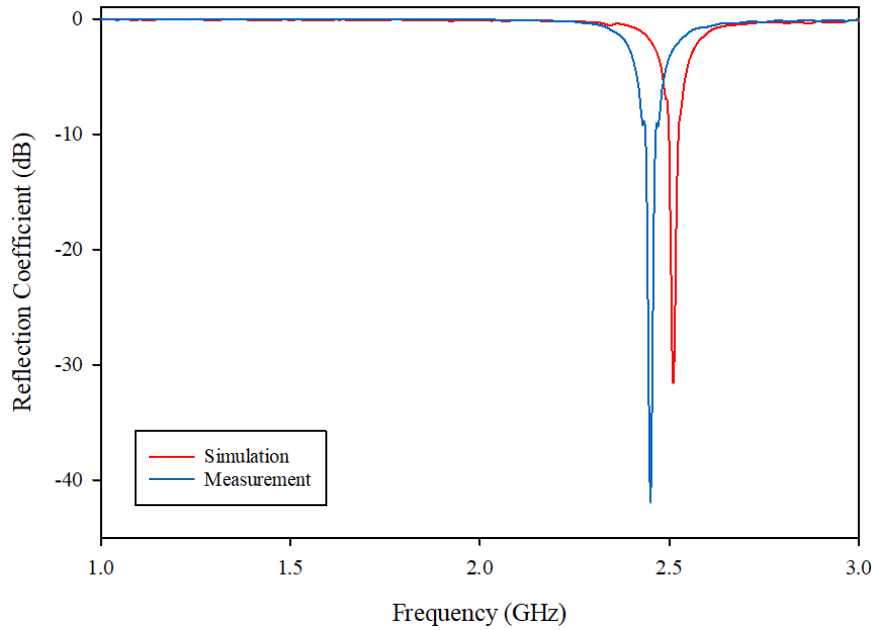


Figure 4.1: S_{11} results for simulated and fabricated rectangular microstrip patch antenna

Table 4.2: Summary of the comparison between S_{11} results for simulated and fabricated rectangular microstrip patch antenna

	Simulated	Fabricated
Resonant Frequency (GHz)	2.51	2.45
Reflection Coefficient (dB)	-19.56	-41.39

The primary focus of this research is to assess the impact of varying levels of impurities on the resonant frequency shift of the fabricated antenna. Therefore, even slight measurement variations must be closely monitored, as they can introduce imperfections into the analysis.

In practical applications, antennas may encounter defects that prevent them from resonating at the desired frequency. In contrast, simulations often represent the ideal design envisioned by the researcher. In this thesis, the simulation conducted using CST Microwave Studio predicted a resonant frequency of 2.45 GHz based on the dimensions outlined in Table 3.5 in Chapter 3. However, the resonant frequency of the fabricated antenna, measured with a

Vector Network Analyzer (VNA), is 2.60 GHz, indicating a discrepancy of 0.15 GHz due to various contributing factors.

One significant source of error in the fabricated antenna is human error. Throughout the design and fabrication stages outlined in Chapter 3, many steps are conducted manually. For instance, while designing the microstrip patch antenna using the Proteus Design Suite, challenges arose concerning the antenna dimensions. The designer had to round off parameter values to fit the maximum length requirements of the Computer Numerical Control (CNC) machine used for cutting, which resulted in size discrepancies between the fabricated and simulated antennas. After fabrication, manual cutting with a Printed Circuit Board (PCB) cutter was necessary to remove excess material.

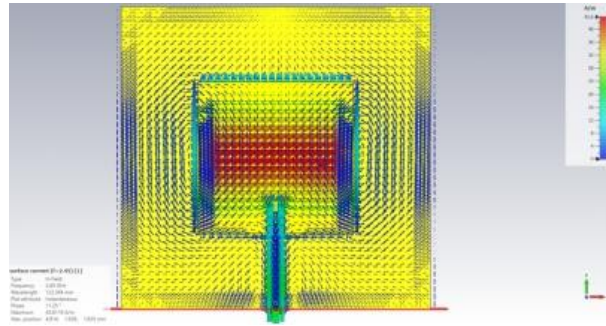
Additionally, the design printed on transparent paper for ultraviolet (UV) exposure did not align with the simulation measurements, as it was initially transferred to AutoCAD for adjustments. During UV exposure, inaccuracies in positioning the film positive on the FR-4 board led to improper degradation of the photoresist coating. This misalignment, caused by the antenna size not matching the original design, necessitated adjustments to the film positive's positioning. Consequently, these errors adversely affected the etching process.

4.3 Feeding Technique

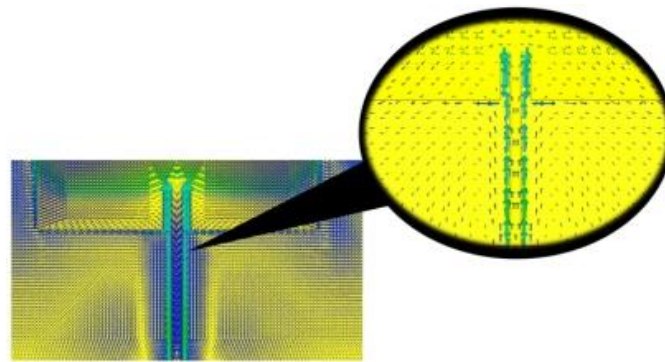
In this sub-chapter, analysis of the feeding technique is presented. As mentioned earlier in Chapter 3, there are two feeding technique that can be implemented into microstrip patch antenna; microstrip feeding and coaxial cable feeding. In this research we need to investigate on which feeding technique is more suitable to be implemented into the designed antenna. Thus, the investigation of the analysis in this sub-chapter focus on the results for current distribution, efficiency, return loss and VSWR.

4.3.1 Analysis of Patch Antenna with Microstrip Feedline Technique

Surface current distribution for MPA with microstrip feedline at 2.45 GHz is shown in Figure 4.2. The density meter and flow of e-field movement inside the antenna are shown in the figure along with the current density.



(a)



(b)

Figure 4.2: Surface current distribution for MPA with microstrip feedline (a) Front view

(b) Transmission Line

The blue color denotes 0 to 4 A/m, indicating a low magnetic field strength at the transmission line in Figure 4.2. At the input port, the current distribution has a very low flow and magnitude, and it gets smaller as it gets closer to the patch. As it moves to the patch, the input port signal is partially lost.

4.3.2 Analysis of Patch Antenna with Coaxial Feeding Technique

The return loss values for a microstrip patch antenna using coaxial feeding are displayed in Figure 4.3. Based on the outcome, it can be deduced that the S_{11} value is -15.55 dB at the same working frequency, 2.45 GHz. When S_{11} is greater than -10 dB, more than 90% of the input power is transmitted to the microstrip patch to produce the resonance signal. Operating frequencies for bandwidth performance range from 2.31 GHz to 2.56 GHz, with a resultant bandwidth value of 0.25 GHz.

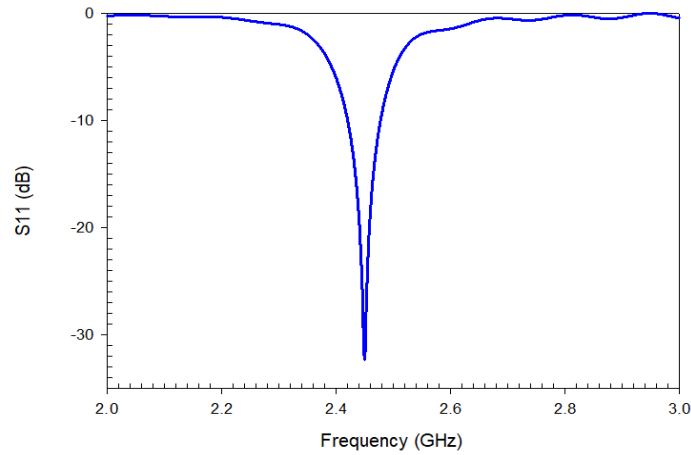
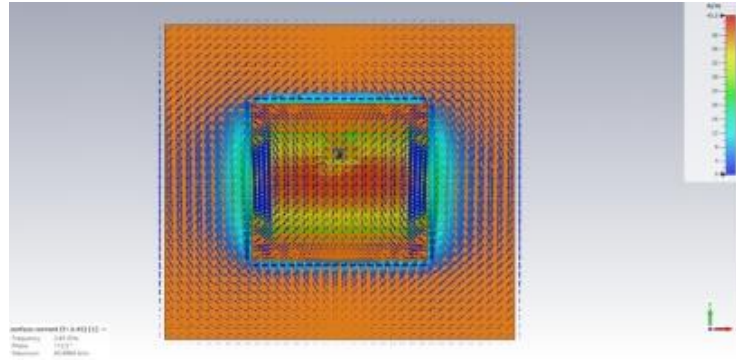
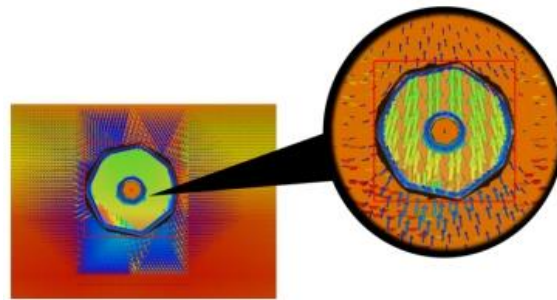


Figure 4.3: Return loss for microstrip patch antenna with coaxial feeding technique

Surface current distribution for MPA with coaxial feed at 2.45 GHz is shown in Figure 4.4. The picture also includes a density meter and displays the flow and density of e-field movement within the antenna.



(a)



(b)

Figure 4.4: Surface current distribution for MPA with coaxial feed

(a) Front view (b) Transmission Line

The magnetic field strength is considerable at the transmission line depicted in Figure 4.3, though, as the color shows 20 to 32 A/m, which is superior to MPA with feedline approach. A coaxial feed line's center conductor enters the substrate and makes direct contact with the patch. As a result, the current distribution is of the optimized amplitude and concentration at the input port, which is situated at the back of the antenna, and it disperses evenly as it approaches the patch. This explains why microstrip feedline performs worse than coaxial feed when comparing performance.

4.3.3 Summary of Patch Antenna Feeding Technique

The comparative S_{11} result between the coaxial and microstrip feeding techniques for MPA is shown in Figure 4.5. The microstrip patch antenna with coaxial feeding approach exhibits greater return loss than the microstrip patch antenna with microstrip feedline by more than -10 dB, according to the results of the S_{11} of the microstrip feedline and coaxial feeding.

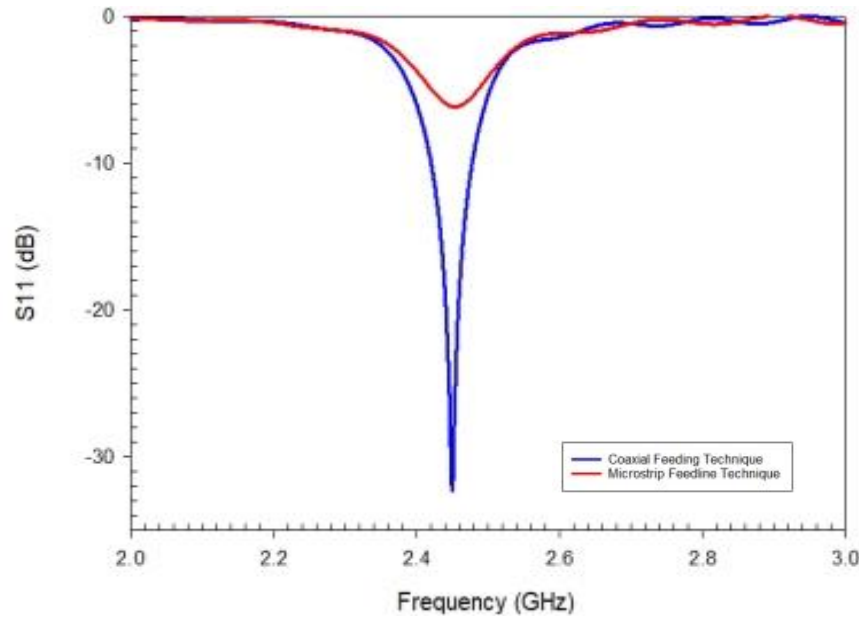


Figure 4.5: S_{11} result comparison between of the microstrip patch antenna with microstrip feedline technique and coaxial feeding technique

Voltage Standing Wave Ratio is a measure of how much the antenna and feedline it is connected to be misaligned (Lee et al., 2011). Figure 4.6 displays the results of the VSWR simulation comparing the microstrip feedline and coaxial feeding. Based on the findings, at 2.45 GHz, the MPA with microstrip feedline has a VSWR of 2.904 while the MPA with coaxial feeding technique is 1.037. More power sent to the antenna and the antenna match the transmission line better with a decreased VSWR.

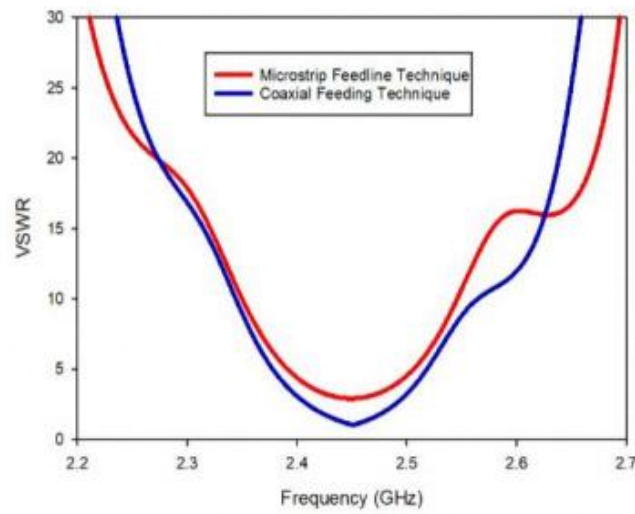


Figure 4.6: VSWR result comparison between of the microstrip patch antenna with microstrip feedline technique and coaxial feeding technique

The comparison between microstrip patch antennas with microstrip feedlines and microstrip patch antennas with coaxial feeding is summarized in Table 4.3. According to Table 4.3, MPA with coaxial feeding technique caused a return loss that was 22.5% higher than MPA with microstrip feedline technology. The VSWR for coaxial feeding approach is lower than the VSWR for microstrip feedline technology, as shown in Table 4.3. In comparison to the microstrip feedline, it demonstrates that the coaxial feeding technology has less mismatch.

Table 4.3: Summary of the comparison between microstrip feedline technique and microstrip patch antenna with coaxial feeding technique.

	Microstrip Feeding Technique	Coaxial Feeding Technique
Resonant Frequency (GHz)	2.45	2.45
Return Loss (dB)	- 6.15	-15.55
Efficiency (%)	40.5	46.6
VSWR	2.94	1.14
Impedance	48.69	50

The impedance of a mismatched antenna less than 50Ω or greater than 50Ω . One of the reasons why this occurred is due to the current that flows from the feeding line technique used in the microstrip patch antenna design (Sultan et al., 2019). Based on the findings, the coaxial feeding technique was chosen due to its superior return loss, efficiency, and impedance matching characteristics compared to the microstrip feedline.

4.4 Minkowski Fractal Antenna

The designation of the antennas is simulated with CST Microwave Studio software to ensure that the antennas specification targets had been achieved. Therefore, the structure of the antennas was analyzed to get the optimized result, which has better efficiency that can acts as an effective signal receiver. Better signal receiver enables the system to have the best performance for FT-NIR level measurement.

The MFA antenna design structure had been optimized by changing the radiating patch radius to achieve the targeted frequency band and bandwidth required to cover the NIR spectrum. As shown in Figure 4.7(a) is the initial rectangular microstrip patch antenna meanwhile final configuration of the proposed Minkowski fractal antennas based on the parameter that has been optimized is shown in Figure 4.7(b) to Figure 4.7(e) and Table 4.4.

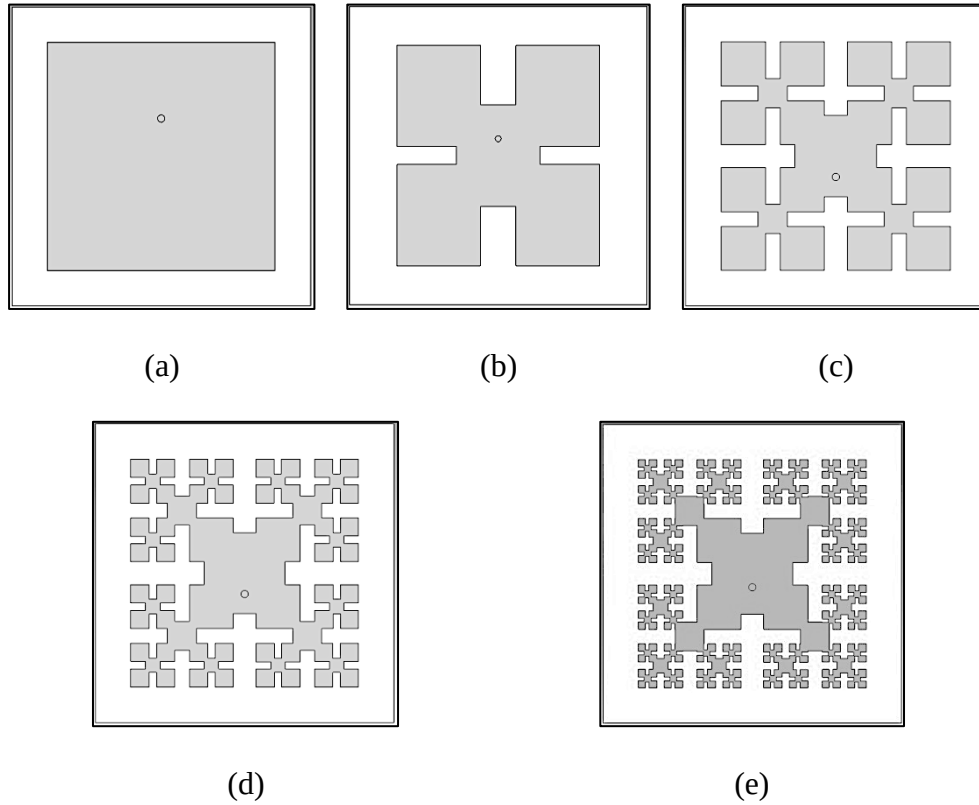


Figure 4.7: Front view of antenna (a) rectangular patch , (b) First iteration MFA, (c) Second iteration MFA, (d) Third iteration MFA, (e) Fourth iteration MFA

Table 4.4: Geometrical Configuration of Minkowski Fractal Antenna

Length of Sides (mm)	Types of Designs				
	Square Patch	First Iteration	Second Iteration	Third Iteration	Fourth Iteration
Patch Width	40.50	38.10	38.86	34.19	33.23
Patch Length	40.50	38.10	38.86	34.19	33.23
Ground Width	50	50	50	50	50
Ground Length	50	50	50	50	50

Figure 4.8 illustrates the comparison between the simulation and measurement results for the first iteration of the Minkowski fractal antenna. In the simulation, the reflection coefficient is recorded at -32.52 dB at 1.834 GHz, while the measured value is -27.48 dB at 1.823 GHz. This indicates that the simulation predicts better impedance matching compared to the measurement, reflecting a difference in performance between the two assessments.

Referring to Figure 4.7(c), the second iteration was introduced to address the limitations observed in the first iteration. By applying the second iteration of the Minkowski fractal structure, the current path on the patch was effectively lengthened, which improved impedance matching and brought the resonant frequency closer to the desired value.

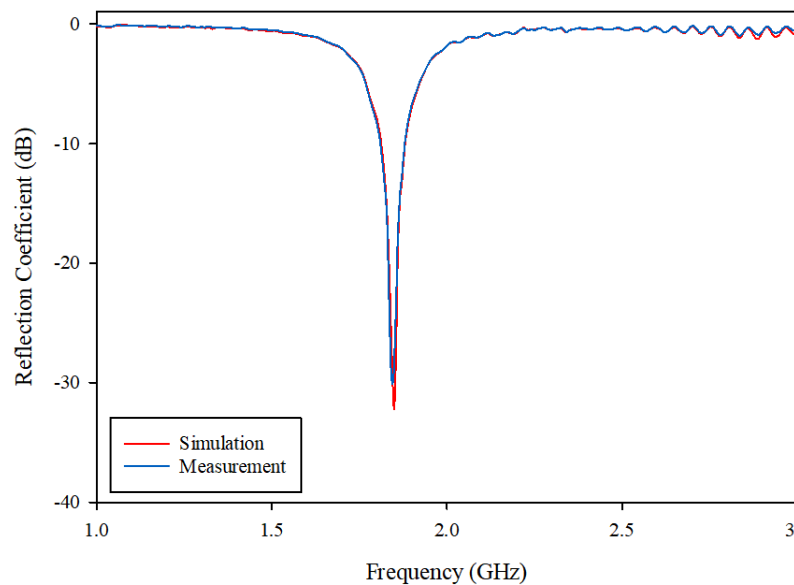


Figure 4.8: Comparison results of return loss between simulation and measurement of first iteration Minkowski fractal antenna.

Thus, simulation on second iteration is done and Figure 4.9 shows the comparison results of return loss between simulation and measurement of second iteration Minkowski fractal antenna. As seen, Figure 4.9 depicts that the value of return loss for simulation and

measurement are -22.13 dB at 1.942 GHz and -33.48 dB at 1.821 GHz, respectively. The value of the measurement result improves to 40.82% better than the simulation result.

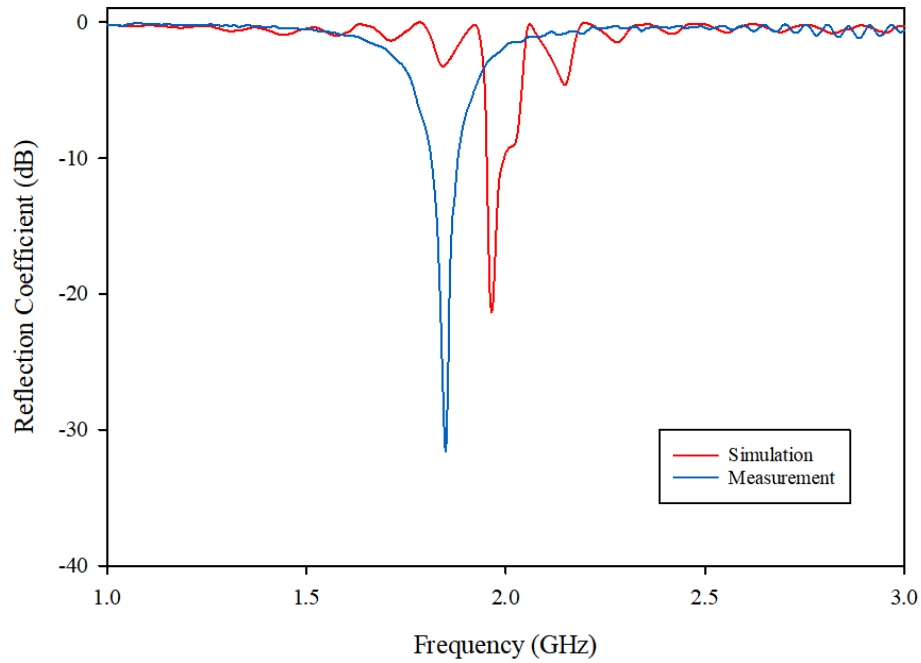


Figure 4.9: Comparison results of return loss between simulation and measurement of second iteration Minkowski fractal antenna.

Further investigations were carried out by simulating the third and fourth iterations of the Minkowski fractal antenna to evaluate the return loss performance and compare the simulated results with the measured data.

Figure 4.10 and Figure 4.11 shows the comparison results of return loss between simulation and measurement of third iteration and forth iteration of Minkowski fractal antenna, respectively. Based on Figure 4.10, the value of the return loss for the simulation has decreased to -31.85 dB at 1.540 GHz. Meanwhile, the measurement decreased to -25.34 dB at 1.881 GHz. Simulations might use idealized models that do not capture all real-world effects, such as fringing fields or coupling with nearby components. These factors can lead to discrepancies in

the performance metrics of Minkowski fractal antennas, such as resonant frequency and reflection coefficient, between simulated predictions and measured outcomes.

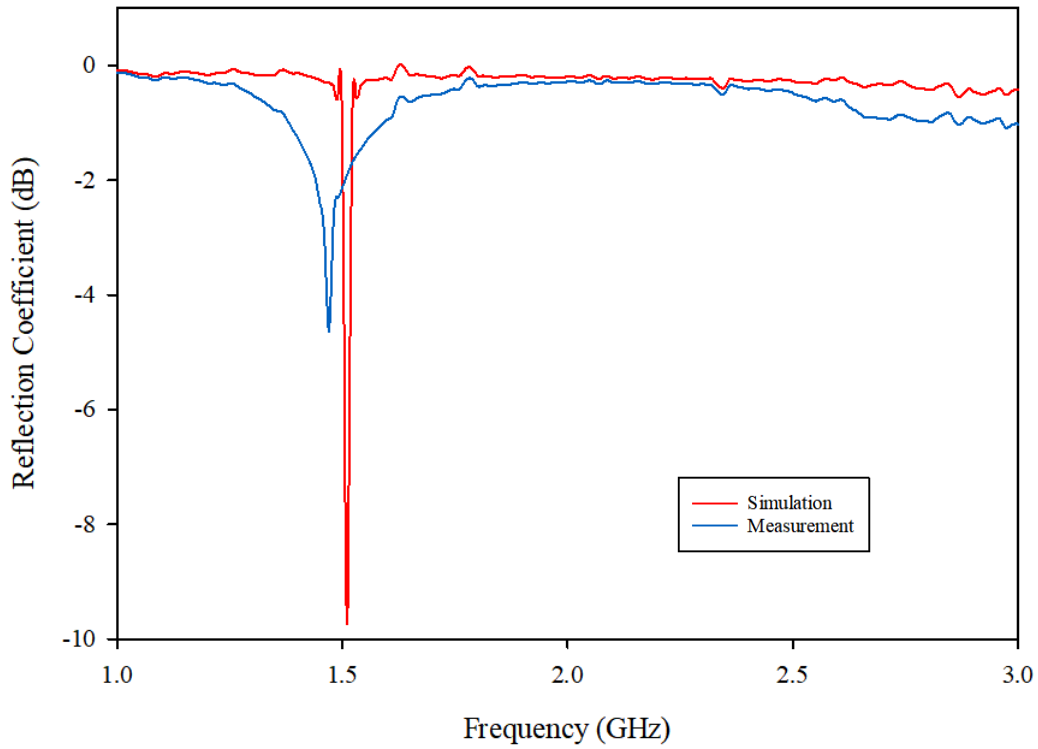


Figure 4.10: Comparison results of return loss between simulation and measurement of third iteration Minkowski fractal antenna

Meanwhile as shown in Figure 4.11, the simulated return loss decreased to -5.96 dB at 1.506 GHz while the measurement obtained from VNA is -4.87 dB at 1.489 GHz. This indicates a slight difference in both return loss and resonant frequency between the simulated and measured results. The lower return loss in the simulation suggests better impedance matching compared to the measurement, which could be attributed to various factors such as fabrication tolerances, material properties, and environmental influences.

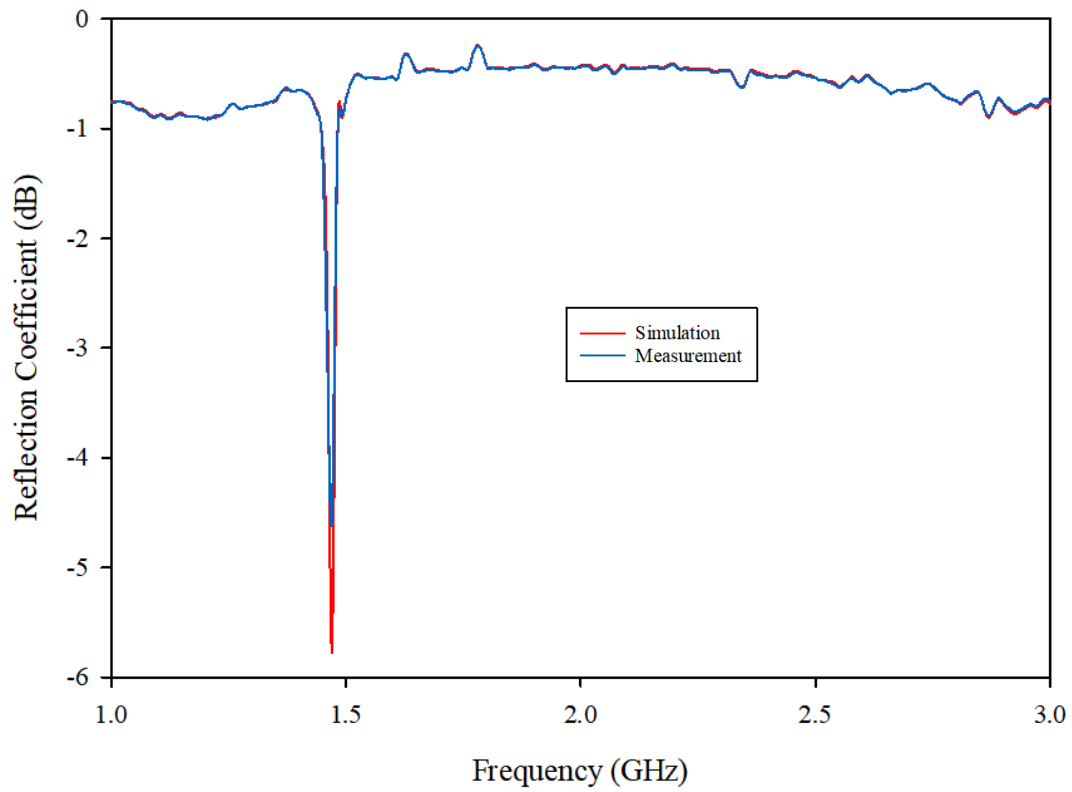


Figure 4.11: Comparison results of return loss between simulation and measurement of fourth iteration Minkowski fractal antenna

Based on Figures 4.8 to 4.11, it is observed that the frequency bands falling below -10 dB for the S_{11} value indicate that the bandwidth becomes narrower with an increasing number of iterations. The optimal number of iterations, yielding the highest fractional bandwidth (FBW) of 44.43% (spanning from 1.79 GHz to 1.89 GHz), occurs at the first iteration of the Minkowski fractal geometry.

4.4.1 Comparison on Rectangular Patch and Minkowski Fractal Antenna

The discussion of the comparison between rectangular patch antenna and first to fourth iteration Minkowski fractal antenna on farfield and current distribution is discussed in this subsection.

4.4.1.1 Farfield (E-plane and H-plane)

A precise receiving antenna with an omnidirectional radiation pattern is essential for accurately measuring electromagnetic field strength in ambient FT-NIR exposure levels around Base Station Towers (BST).

The rectangular patch antenna operates at higher frequencies, specifically 2.45 GHz, where the radiation pattern exhibits a butterfly shape in both the E-field and H-field due to the influence of higher-order modes. In the first iteration, the antenna operates at 1.834 GHz, producing partial eight-shaped patterns in both the E-field and H-field.

In the second iteration, with operation at 1.821 GHz, complete eight-shaped omnidirectional patterns are observed in both fields. The third iteration operates at 1.481 GHz, again resulting in an eight-shaped pattern. Finally, in the fourth iteration, the antenna functions at 1.480 GHz, where a partial omnidirectional pattern appears in both the E-field and H-field. The simulated far-field patterns for the E-field and H-field are illustrated in Figures 4.12 and 4.13, respectively.

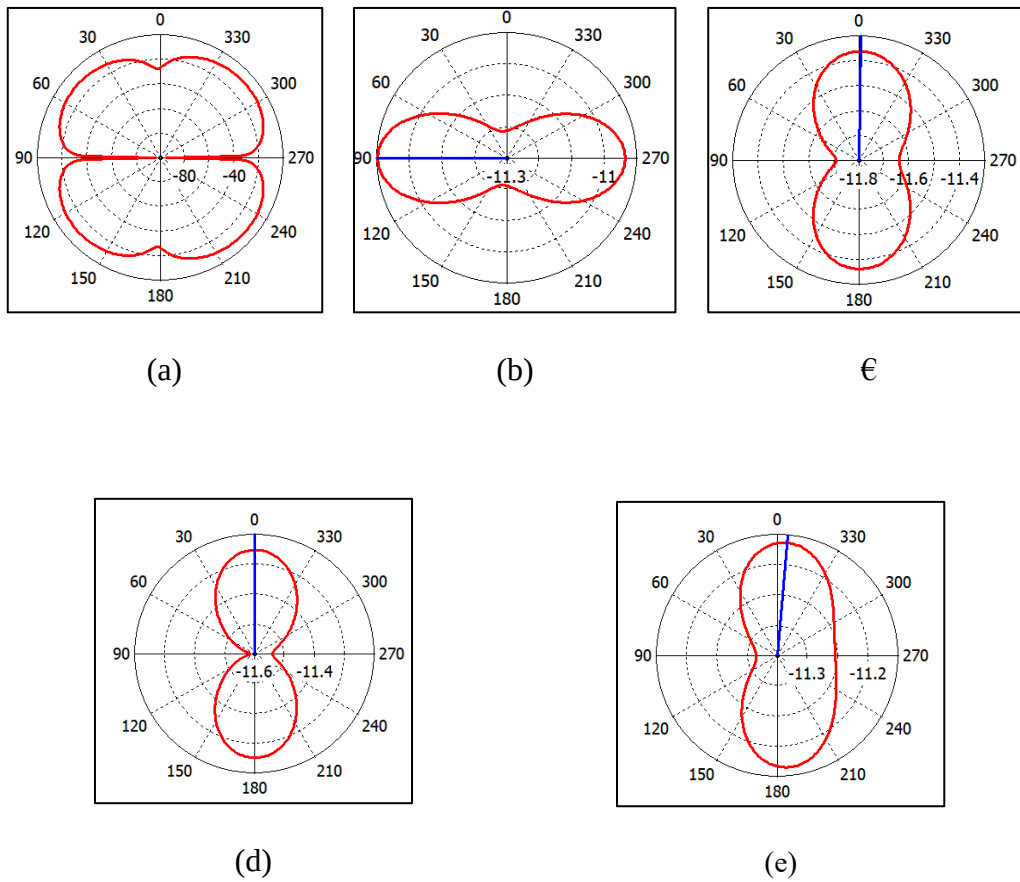


Figure 4.12: *E*-Plane pattern comparison (a) Square patch, (b) First iteration, (c) Second iteration, (d) Third iteration, and (e) Fourth iteration

E-field, typically exhibits a more uniform and broader beamwidth with a primary lobe and several minor side lobes. The pattern may resemble a conventional dipole pattern. At higher frequencies, the rectangular patch antenna may display a more distorted pattern due to higher-order modes, resulting in a butterfly shape. *E*-field patterns for Minkowski are often more complex, with distinct shapes such as eight-shaped or partial butterfly patterns. These can change significantly with each iteration, reflecting the fractal nature. In subsequent iterations, the patterns generally remain consistent, with some adjustments in bandwidth and gain, but major changes in shape are less pronounced compared to fractal designs. Minkowski fractal

antennas often show better omnidirectional properties, particularly in lower frequency iterations.

Figure 4.13 shows the H -plane comparison of MPA and MFA with iterations. The H -plane pattern usually shows a similar broadside directionality, but with less pronounced variation compared to the E-field. Similar to the E-field, the H-field patterns also tend to show complexity and can exhibit omnidirectional characteristics, especially in lower frequency iterations. As iterations progress, both E-field and H-field patterns evolve. For instance, the first iteration might show partial eight-shaped patterns, while subsequent iterations refine these patterns into more pronounced omnidirectional shapes, often leading to better overall performance in terms of gain and bandwidth.

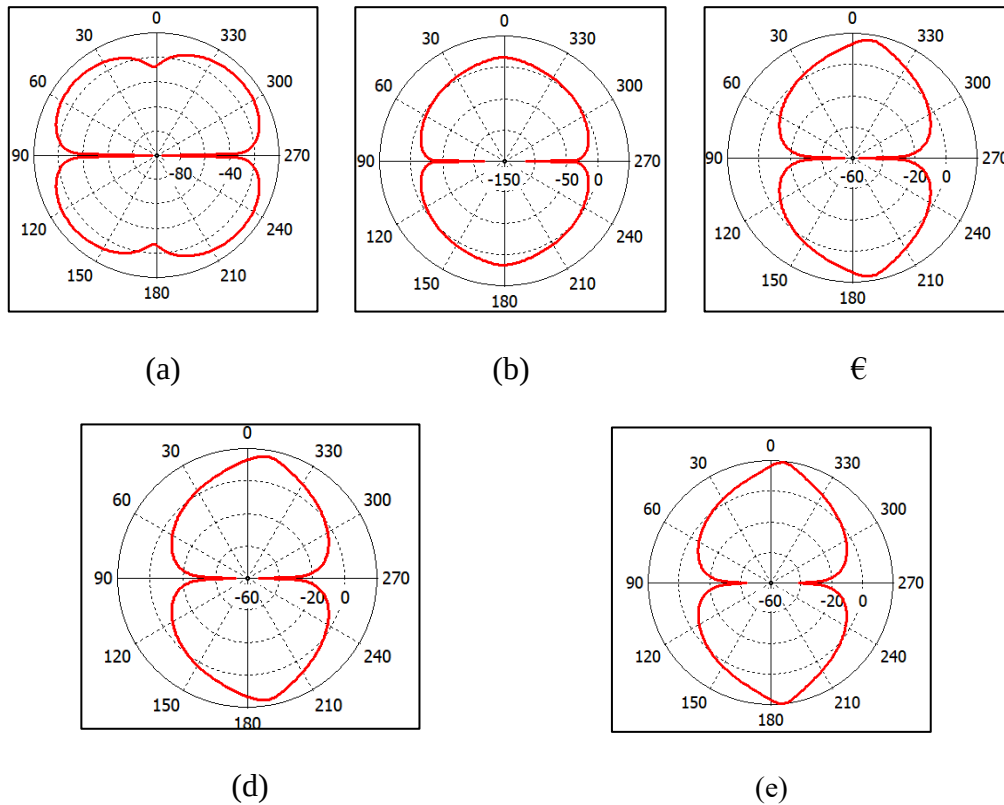


Figure 4.13: H -Plane pattern comparison (a) Square patch, (b) First iteration, (c) Second iteration, (d) Third iteration, and (e) Fourth iteration

4.4.1.2 Surface Current Distribution

Figure 4.14 depicts the proposed antenna's surface current distribution. Figure 4.11(a) depicts the antenna operating at 2.45 GHz, where the maximum current density is concentrated at the center of the radiating patch, particularly at the feeding point. This indicates an increase in the number of modes as the frequency rises.

Figure 4.14(b) shows the antenna at 1.834 GHz, with maximum current density shifting to the edge of the radiating patch. Figures 4.14(c) and (d) present the antenna operating at frequencies 1.821 GHz and 1.481 GHz, respectively, where the current density is notably high at both the center and the edge of the radiating patch. Finally, Figure 4.14(d) illustrates the antenna operating at 1.480 GHz, again displaying maximum current density at both the center and edge of the radiating patch. This distribution highlights how current density varies with frequency, reflecting the changing mode behavior within the antenna design.

As the frequency decreases from 2.45 GHz to 1.480 GHz, the surface current distribution shifts from a strong central concentration to a more balanced distribution involving both the center and edges of the radiating patch. This change reflects the transition from higher-order modes to a mix of lower-order modes, highlighting the antenna's versatility in utilizing its structure for effective radiation across different frequencies.

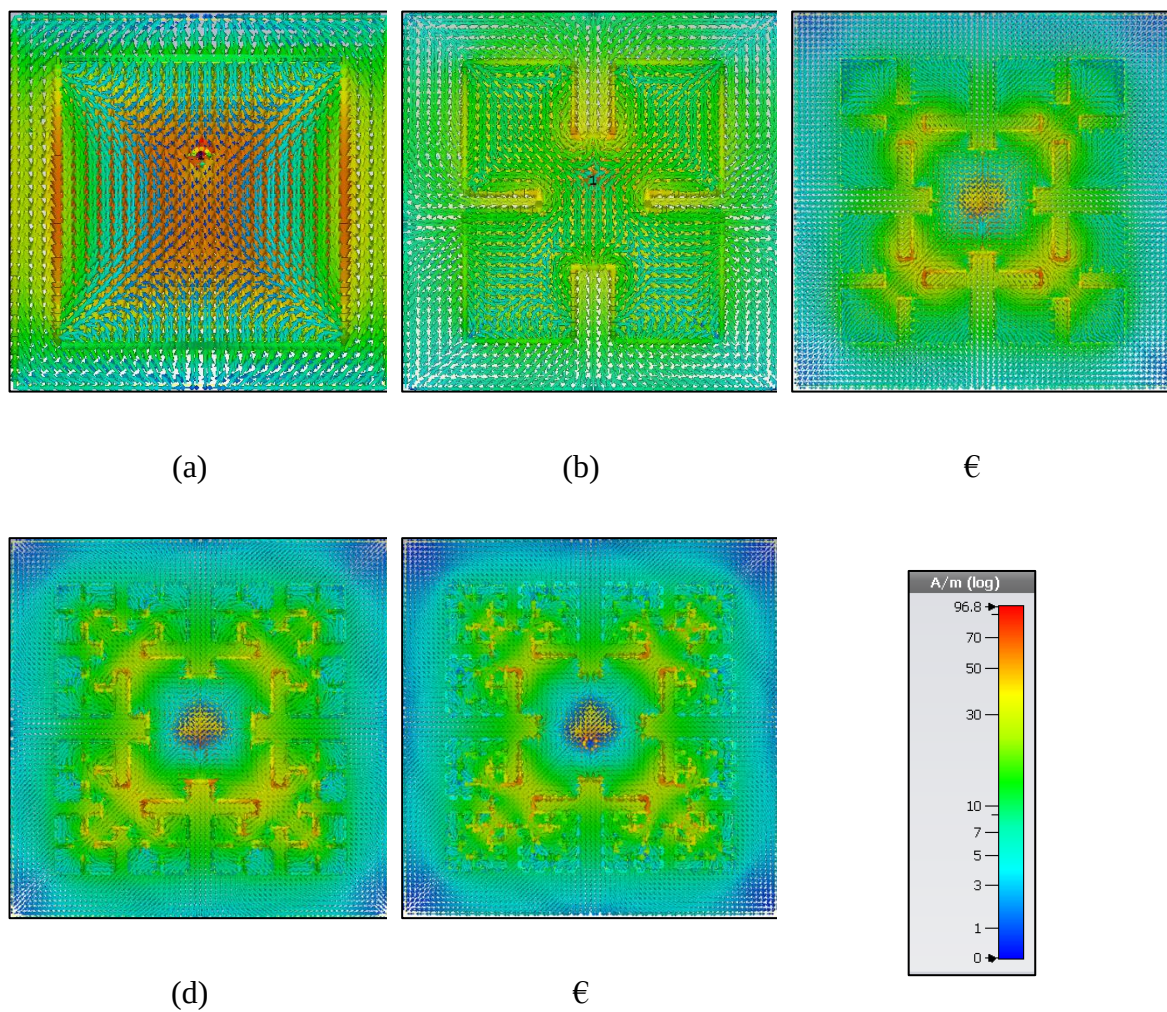


Figure 4.14: Surface current distribution (a) Square patch, (b) First iteration, (c) Second iteration, (d) Third iteration, and (e) Fourth iteration

4.4.1.3 Summary

The proposed Minkowski fractal antenna is designed to assess the impact of impurities in seafood products on their dielectric properties and resonant frequency. This antenna not only aids in detecting foodborne pathogens but also facilitates timely and efficient management measures.

Key factors in determining the antenna's sensitivity include the selected operating frequency, the size and properties of the sample dielectric, and the substrate material (Sultan et al., 2019). The return loss, which is the ratio of reflected power to input power, must be less than -10 dB to ensure appropriate impedance matching and effective operation within the frequency range of 1 GHz to 3 GHz.

A highly sensitive antenna can effectively detect impurities, enabling rapid screening of food samples for bacterial contamination while keeping costs low for consumers (Yahaya et al., 2014). The Minkowski fractal antenna, with its high sensitivity to bacterial detection, operates at frequencies increasingly distant from the resonant frequency of 2.45 GHz, while maintaining low loss.

As the number of iterations increases, the fractal structure of the antenna becomes more complex, which enhances its directivity, resulting in a narrower 3 dB beamwidth for the E-plane and H-plane radiation patterns. Additionally, the surface current density remains uniform across all four iterations of the antenna. The increase in iterations also correlates with higher gain, demonstrating the suitability of the Minkowski fractal antenna for detecting microorganisms in seafood products. Table 4.5 provides a summary of the simulated reflection coefficient, gain, VSWR, and patch area.

Moreover, with more iterations, the return losses of a Minkowski fractal antenna typically decrease. Each iteration introduces additional complexity to the antenna's geometry, enhancing impedance matching across a broader range of frequencies. This allows for more efficient energy transfer from the feed line to the antenna, reducing reflected power and thus lowering return loss.

Apart from that, more iterations can lead to a more uniform and optimized surface current distribution across the antenna. This optimized distribution enhances the radiation efficiency

and helps in minimizing the reflection of power. As iterations progress, the antenna design can minimize resistive losses at resonant frequencies. This improved efficiency means less power is reflected back, contributing to lower return loss values.

Table 4.5: Summary of the measurement result for Minkowski Fractal Antenna

Characteristics	Types of Fractals				
	Square Patch	First Iteration	Second Iteration	Third Iteration	Fourth Iteration
Frequency (GHz)	2.450	1.834	1.821	1.481	1.480
Reflection Coefficient (dB)	-41.39	-32.52	-33.48	-5.34	-4.87
VSWR	3.45	3.56	3.91	4.13	4.52
Area of patch (mm ²)	1.016	1.141	1.266	1.374	1.709

The proposed antennas are fabricated and characterized with Vector Network Analyser (VNA). The antenna is fabricated on Roger RO4003C substrate material with thickness, h of 0.04 mm and relative dielectric constant, ϵ_r of 3.38. Figure 4.15 shows the fabricated antennas.

Figure 4.16 and Table 4.6 shows measured reflection coefficient or return loss (S_{11}) of the fabricated antennas. However, the results from the VNA measurement are different from the simulation result. The difference in the results is due to the limitation of the experiment set up such as the equipment calibration and environment issues.

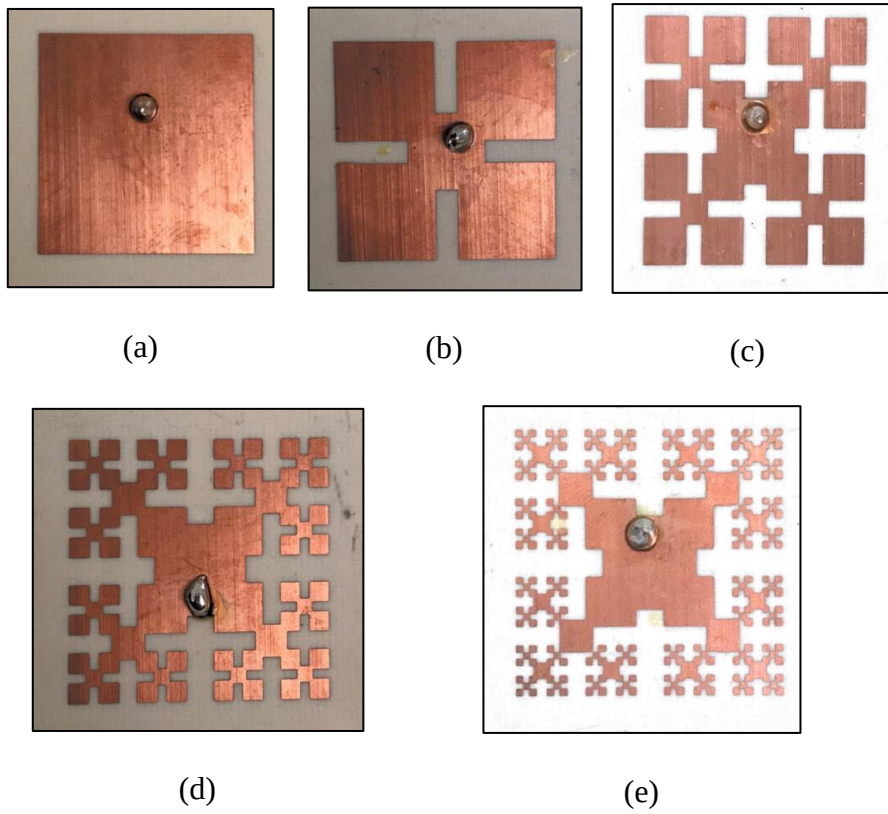


Figure 4.15: Fabricated antenna (a) Square patch, (b) First iteration, (c) Second iteration, (d) Third iteration, (e) Fourth iteration

As iterations progress, the antenna design can minimize resistive losses at resonant frequencies. This improved efficiency means less power is reflected back, contributing to lower return loss values.

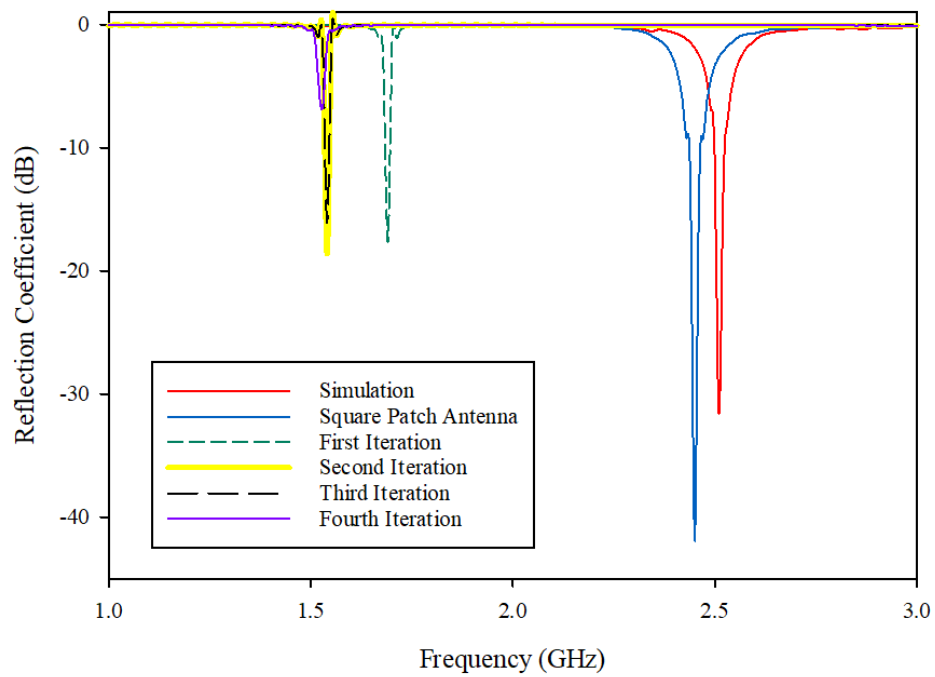


Figure 4.16: Reflection coefficient comparison

Table 4.6: Summary Measurement Results of Minkowski Fractal Antenna

Characteristics	Types of Fractals				
	Square Patch	First Iteration	Second Iteration	Third Iteration	Fourth Iteration
Frequency (GHz)	2.450	1.834	1.821	1.481	1.480
Reflection Coefficient (dB)	-41.39	-32.52	-33.48	-5.34	-4.87

4.5 Analysis of Resonant Frequency and Reflection Coefficient

Salt and sugar solutions have significantly different permittivity value compared to regular water. These differences affect the performance of the antenna including its resonant frequency, bandwidth, radiation pattern, and efficiency.

When designing a microstrip patch antenna on a salt or sugar solution, several factors need to be considered:

- i. **Dielectric Constant:** The dielectric constant of the salt or sugar solution impact the effective permittivity of the substrate. This change in permittivity alter the effective electrical length of the patch and can shift the resonant frequency of the antenna.
- ii. **Substrate Thickness:** The thickness of the solution layer influences the overall dimensions and impedance characteristics of the antenna. It may require adjusting the dimensions of the patch and the feed structure to achieve the desired resonance and impedance matching.
- iii. **Losses:** Saltwater, in particular, can introduce significant losses due to its high conductivity. These losses can reduce the efficiency and radiation performance of the antenna. Careful consideration must be given to mitigate the effects of losses through proper design techniques, such as optimizing the ground plane and using high-quality conducting materials.
- iv. **Substrate Stability:** Salt and sugar solutions can be corrosive and may affect the structural integrity and stability of the antenna over time. The materials used for the patch, ground plane, and feed lines should be resistant to corrosion and able to withstand the environmental conditions.

The design and performance of microstrip patch antennas on salt and sugar solutions may differ significantly from conventional designs. Extensive experimentation and characterization would be required to understand the specific behaviour of the antenna in this unique substrate environment. Further explanation on the analysis for pure solution, salt and sugar solution further discussed on following sub-chapter.

4.5.1 Analysis on Pure Solution

When comparing an antenna in a free space medium to one in pure water, the measured parameter is the reflection coefficient. Regarding resonant frequency, the results from the VNA are reliable. Unfortunately, the reflection coefficient of the pure solution decreases rapidly from -13.3 dB. This should not occur, as the power loss in a free-space medium is expected to be lower than in a pure solution medium. This is because there is less resonance resistance in free space compared to any solution medium. Therefore, the lower the resonance resistance, the lower the reflection coefficient.

Several factors may contribute to this error. The pure solution could have been contaminated beforehand, as it is stored in a recycling container. Unwanted impurities in the container may have altered the dielectric properties of the pure solution. Additionally, the apparatus setup might also affect the reflection coefficient readings. Proper adjustments are needed to ensure the fabricated antenna operates precisely at 2.60 GHz. While 2.60 GHz can be achieved, the exact value of the original reflection coefficient may not be successfully attained. This is due to the readings being volatile and highly sensitive to any movement of the antenna, making the reflection coefficient for the pure solution easily affected by surrounding conditions.

4.5.2 Analysis on Salt Solution

Figure 4.17 shows the final position of the resonant frequency for 50g of salt. From the VNA result, the resonant frequency is shifted to the right hand from the origin with a value of 2.52 GHz, whereas for the reflection coefficient, -7.2 dB is obtained.

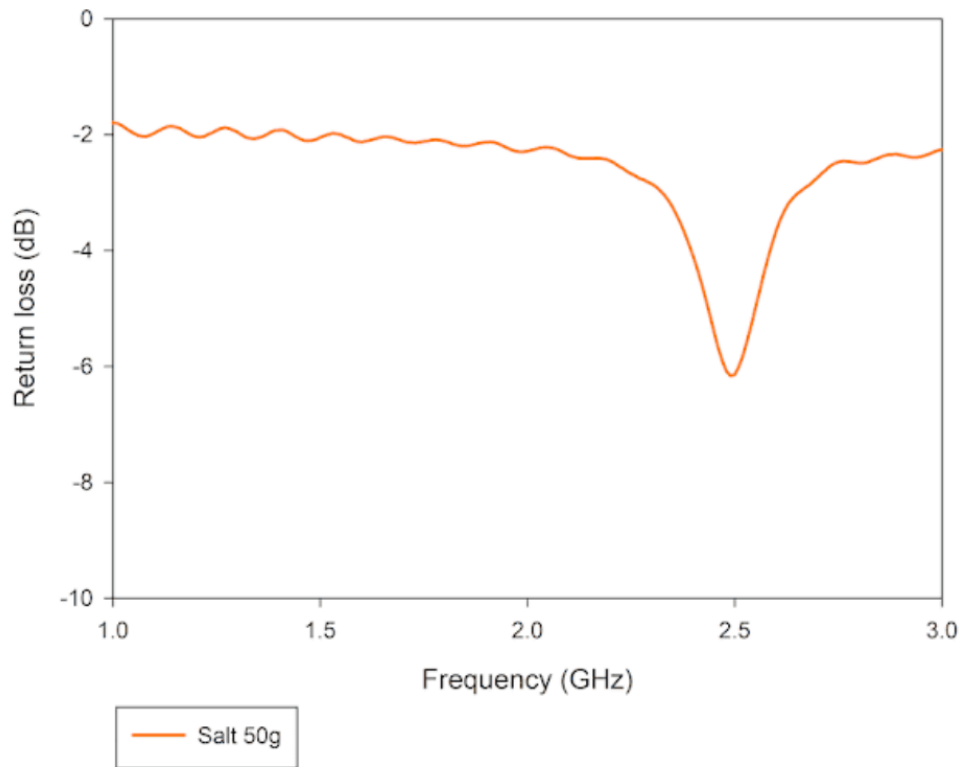


Figure 4.17: Reflection coefficient result for 50 g of salt

With additional of 50g of salt, the result from the VNA as in Figure 4.18 is obtained. With the increment of salt, small shifting can be observed when compared to 50g of salt. The differences of resonant frequency obtained for 100 g of salt is 2.54 GHz. For the reflection coefficient, -6.5 dB is obtained. The addition of 50 g of salt alters the dielectric properties of the surrounding medium, increasing its dielectric constant. This can lead to a higher resonant frequency due to the change in how the antenna interacts with the medium.

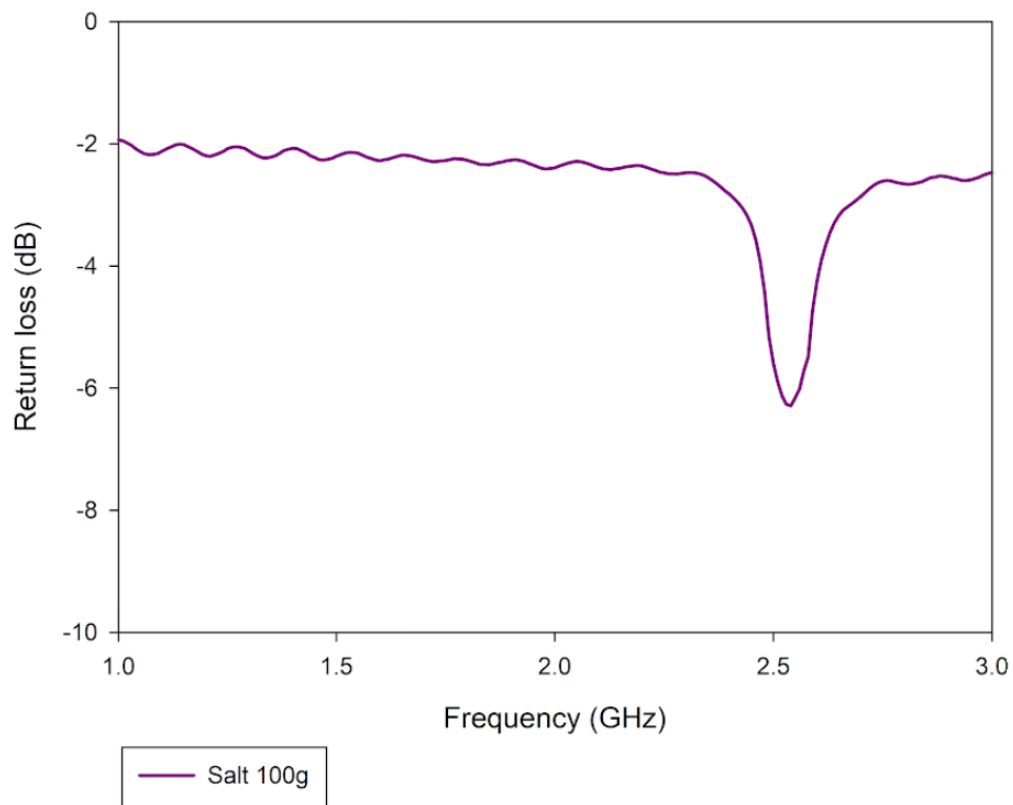


Figure 4.18: Reflection coefficient result for 100 g of salt

Meanwhile, for 150 g of salt, the resonant frequency is shifting further to the right with a value of 2.60 GHz. With a difference of 0.12 GHz from the original resonant frequency, the reflection coefficient increases more rapidly up to -7.8 dB. The result from the VNA is shown in Figure 4.19. A reflection coefficient of -7.8 dB indicates some power is reflected back, which suggests that the antenna may not be perfectly matched to the new medium. The shift in resonant frequency combined with the reflection coefficient implies that energy is being lost, possibly due to changes in the surrounding medium's properties.

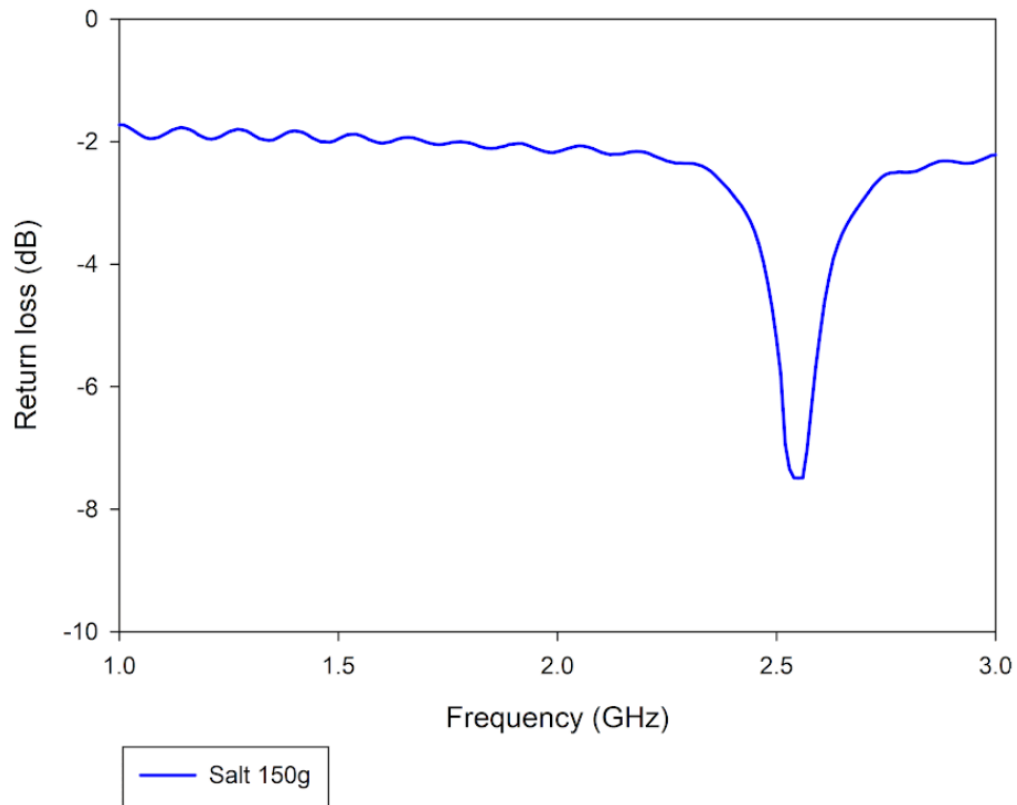


Figure 4.19: Reflection coefficient result for 150 g of salt

For 200 g of salt, the resonant frequency is shifting more further to the right with a value of 2.62 GHz. With a difference of 0.12 GHz from the original resonant frequency, the reflection coefficient increases more rapidly until -8.6 dB. As the antenna is designed to operate within a specific frequency range, changes in the medium's properties can affect how the antenna radiates energy. The resulting shift in resonant frequency is a response to these changes. The result from the VNA is depicted as in Figure 4.20.

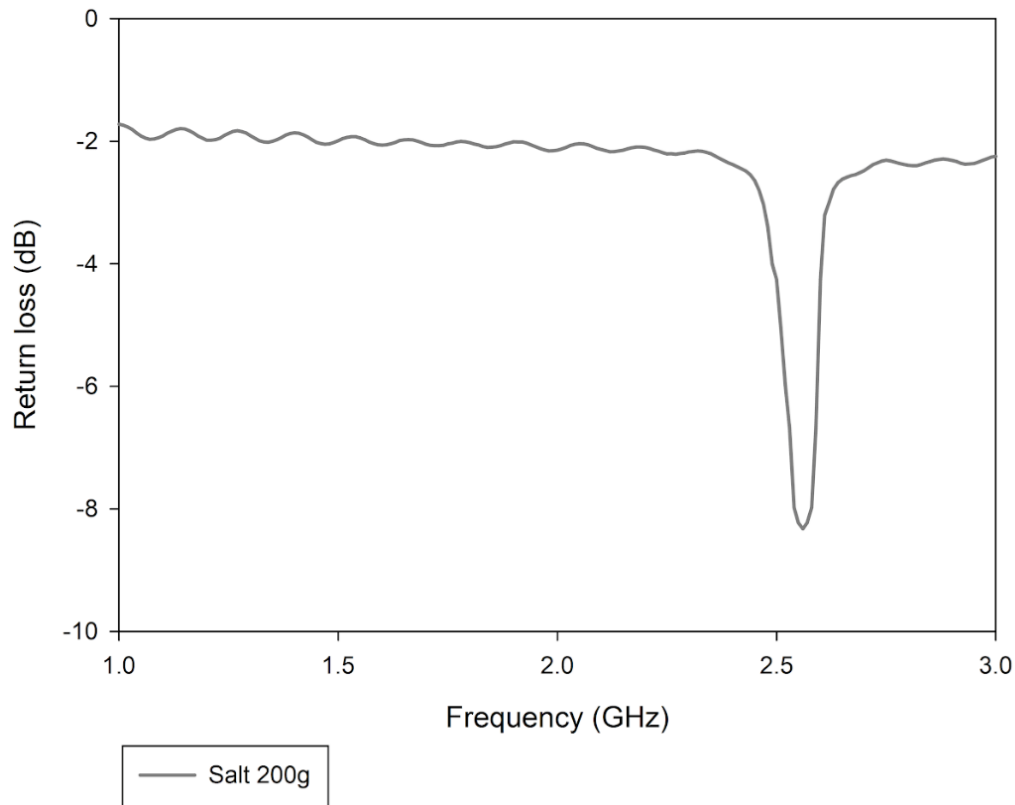


Figure 4.20: Reflection coefficient result for 200 g of salt

Lastly, for 250 g of salt, the resonant frequency is shifting more further to the right with a value of 2.64 GHz. With a difference of 0.14 GHz from the original resonant frequency, the reflection coefficient increases more rapidly until -8.8 dB. The observed shift in resonant frequency and the resulting reflection coefficient suggest that the addition of salt significantly impacts the antenna's performance by altering its dielectric environment and impedance characteristics. The result from the VNA is shown in Figure 4.21.

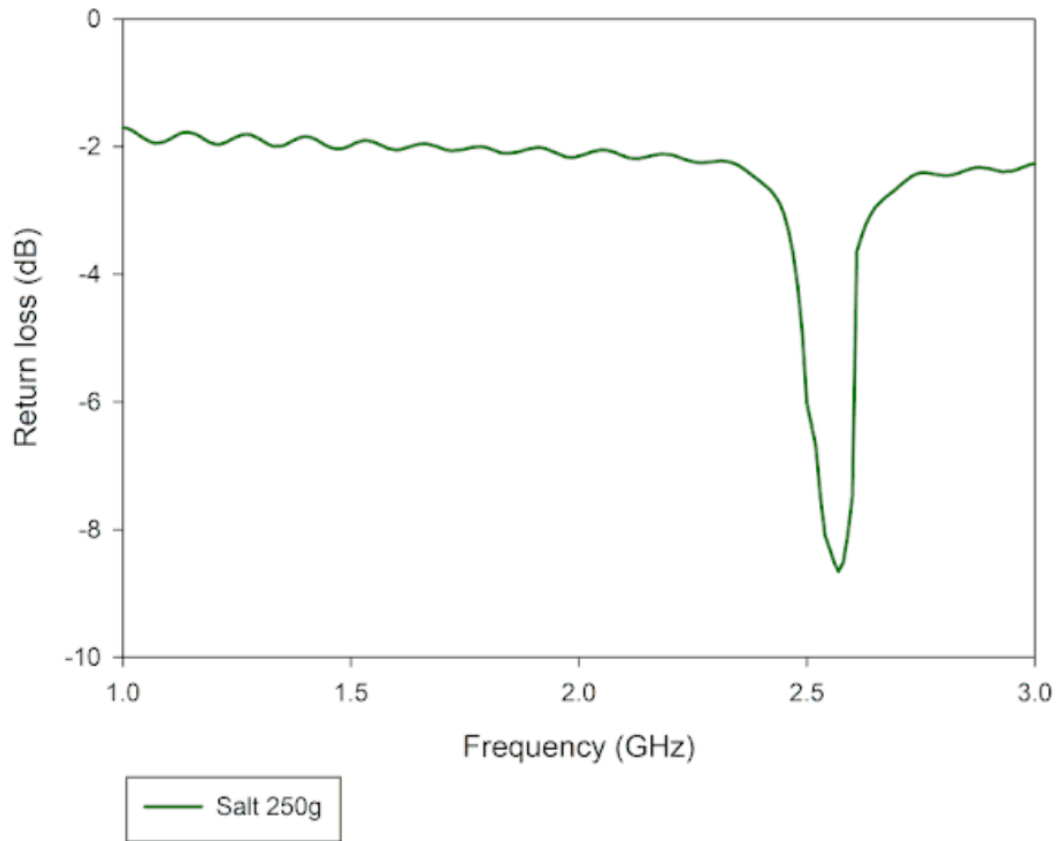


Figure 4.21: Reflection coefficient result for 250 g of salt

Figure 4.22 shows the comparison of the resonant frequency and return loss obtained for salt solution. By referring to Figure 4.22, the original resonant frequency is shifted accordingly to the addition of salt in the pure solution. The shifting is mostly to the right hand from the original radiated frequency. As the concentration increases, the shifting has been shifted further to the right. Thus, the result is reasonable with the data gain from the research paper. Not only that, the increment of the reflection coefficient is parallel with the increment of salt.

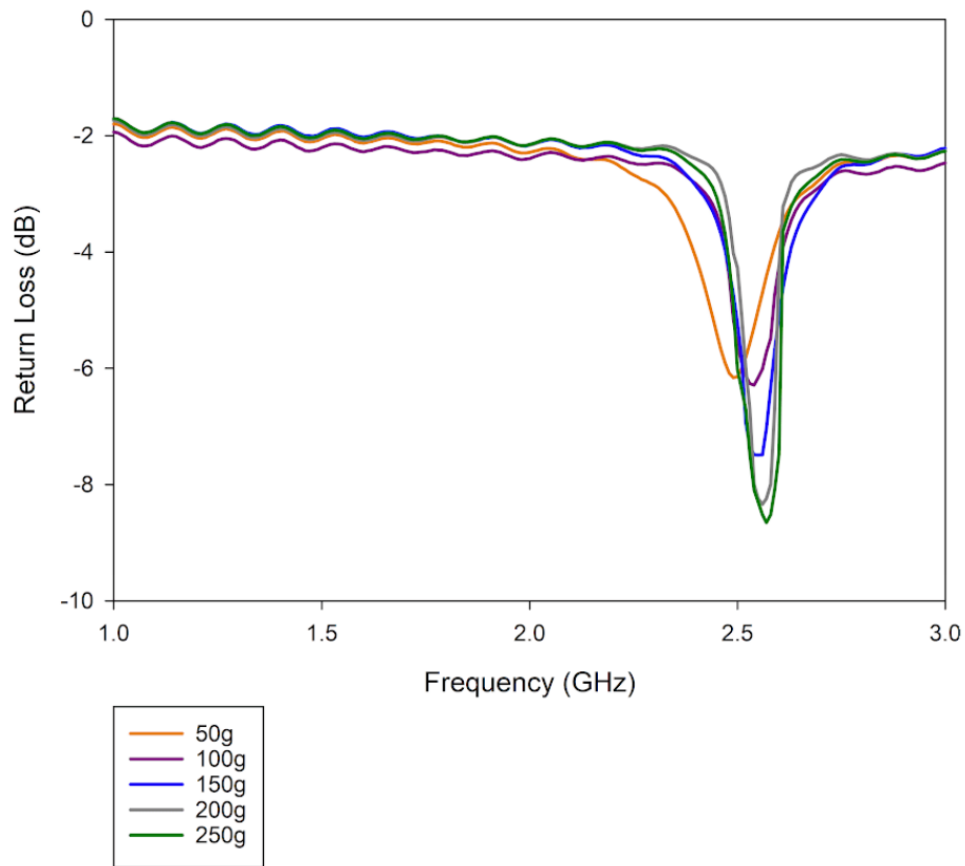


Figure 4.22: Comparison of the resonant frequency and reflection coefficient obtained for salt solution

Initially, the fabricated antenna is always tested without any solution to make sure the benchmark of the original resonant frequency is achieved. After the resonant frequency of 2.50 GHz is achieved, then, the salt solution poured inside the container. The same incident occurs for the salt solution whereby the initial reflection coefficient for 50g of salt is lower than the reflection coefficient of the original resonant frequency. The main reason for this unwanted result is the improper setup for the antenna in the container. As already being mention, any slight movement on the antenna cause the reading on the VNA to be more inaccurate. During the calibration of the antenna to achieve 2.50 GHz, the reflection coefficient might be lower

than -13.3 dB which make the reflection coefficient still under -13.3 dB although in a different medium.

4.5.3 Analysis on Sugar Solution

For 50g of sugar, the resonant frequency is shifting more further to the right with a value of 2.52 GHz. With a difference of 0.12 GHz from the original resonant frequency, the reflection coefficient increases more rapidly until -11.6 dB. The result from the VNA is as in Figure 4.23.

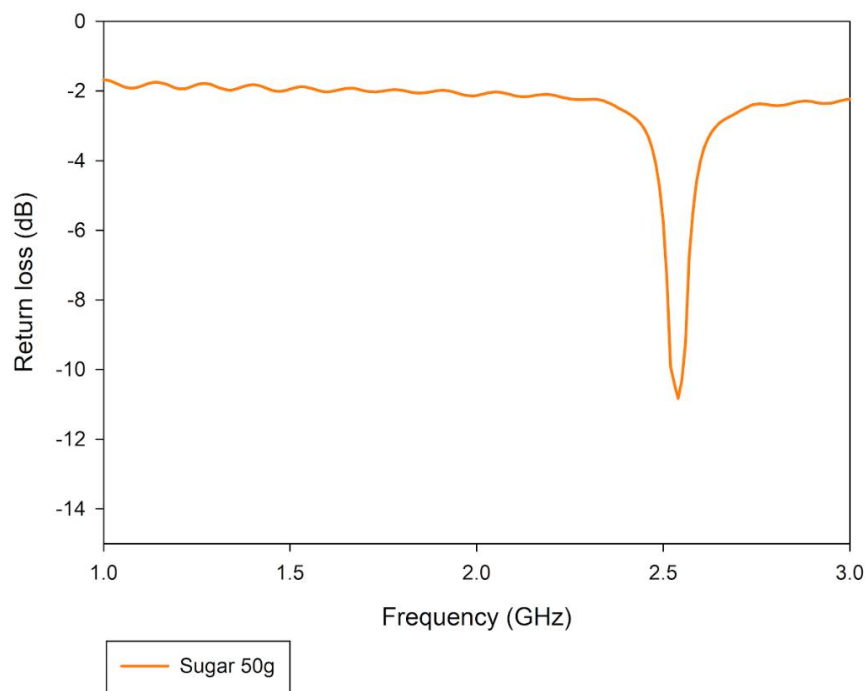


Figure 4.23: Reflection coefficient result for 50 g of sugar

For 100g of sugar, the resonant frequency is shifting more further to the right with a value of 2.54 GHz. With a difference of 0.12 GHz from the original resonant frequency, the reflection coefficient increases more rapidly until -11.4 dB. The addition of sugar affects the dielectric properties of the surrounding medium, typically increasing the dielectric constant.

This can result in a further shift in the resonant frequency as the antenna's response changes to accommodate the new medium. The result from the VNA is as in Figure 4.24.

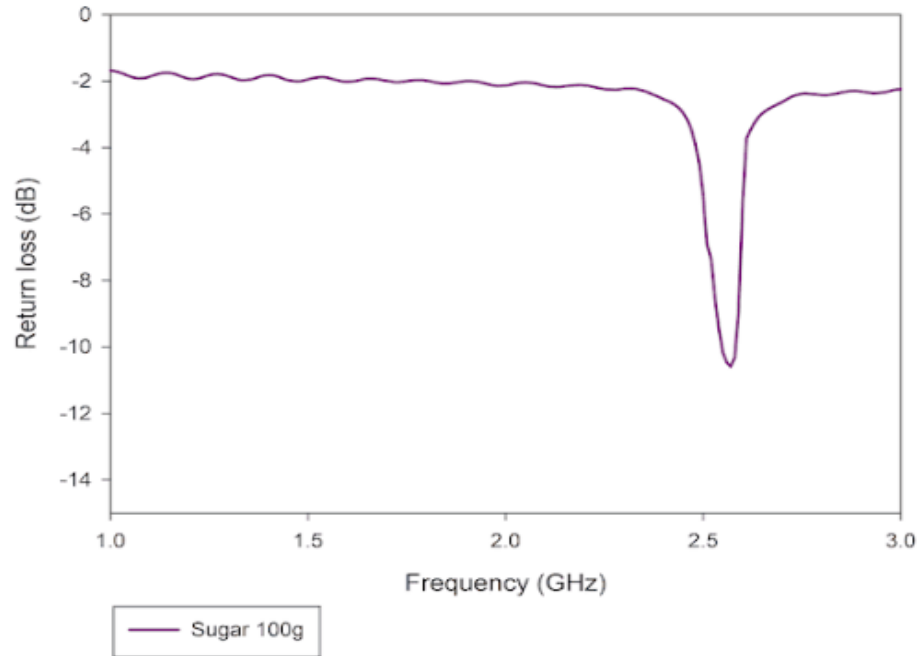


Figure 4.24: Reflection coefficient result for 100 g of sugar

Meanwhile, for 150g of sugar, the resonant frequency is shifting more further to the right with a value of 2.56 GHz. With a difference of 0.12 GHz from the original resonant frequency, the reflection coefficient increases more rapidly until -11.2 dB. As more sugar is introduced, the loading effect on the antenna increases. This loading alters the antenna's resonant characteristics, pushing the frequency higher. The result from the VNA is as in Figure 4.25.

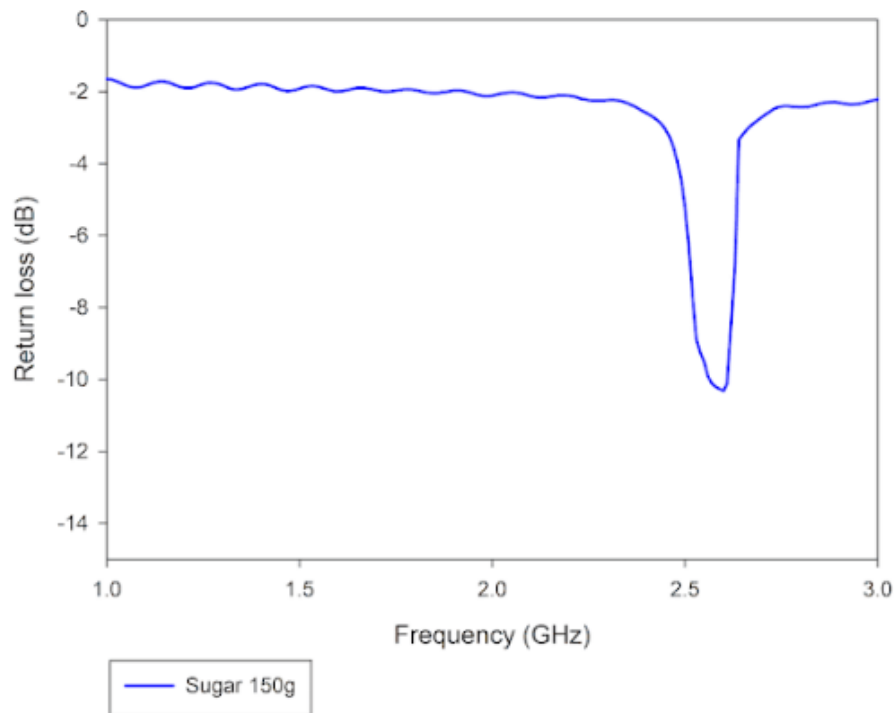


Figure 4.25: Reflection coefficient result for 150 g of sugar

For 200g of sugar, the resonant frequency is shifting more further to the right with a value of 2.6 GHz. With a difference of 0.12 GHz from the original resonant frequency, the reflection coefficient increases more rapidly until -8.8 dB. The change in the dielectric environment due to the sugar may lead to poorer impedance matching at the original resonant frequency, which could require a further shift in frequency to achieve optimal performance. The result from the VNA is as in Figure 4.26.

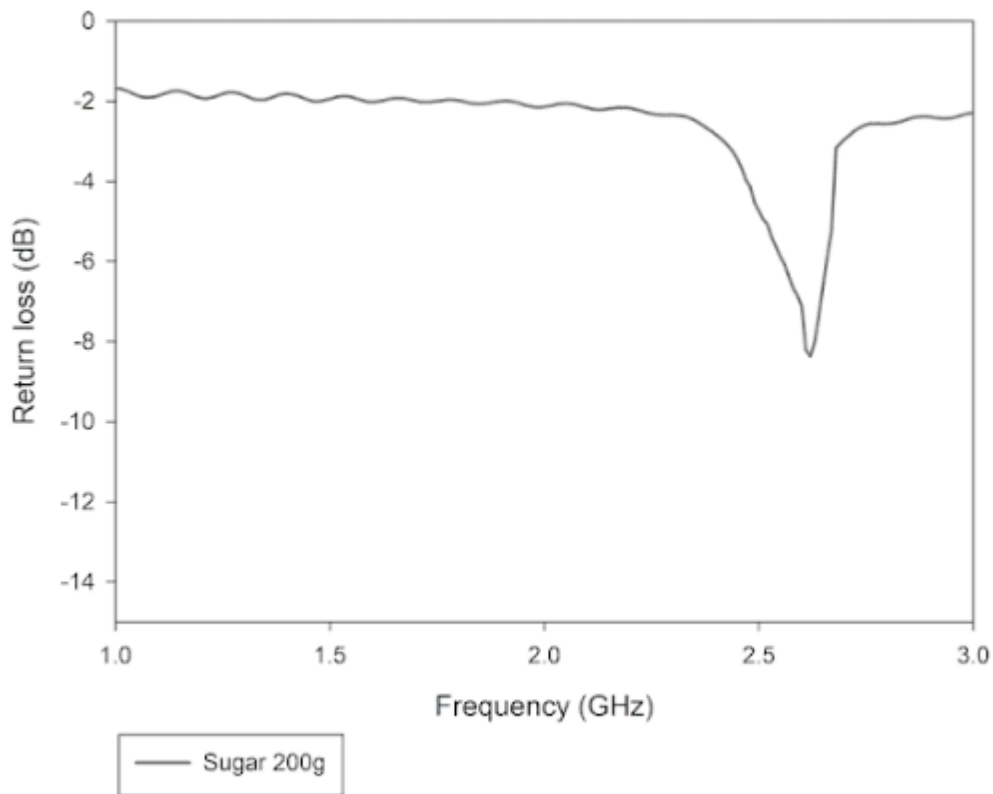


Figure 4.26: Reflection coefficient result for 200 g of sugar

Lastly, for 250g of sugar, the resonant frequency is shifting more further to the right with a value of 2.7 GHz. With a difference of 0.12 GHz from the original resonant frequency, the reflection coefficient increases more rapidly until -8.2 dB. The result from the VNA is as in Figure 4.27.

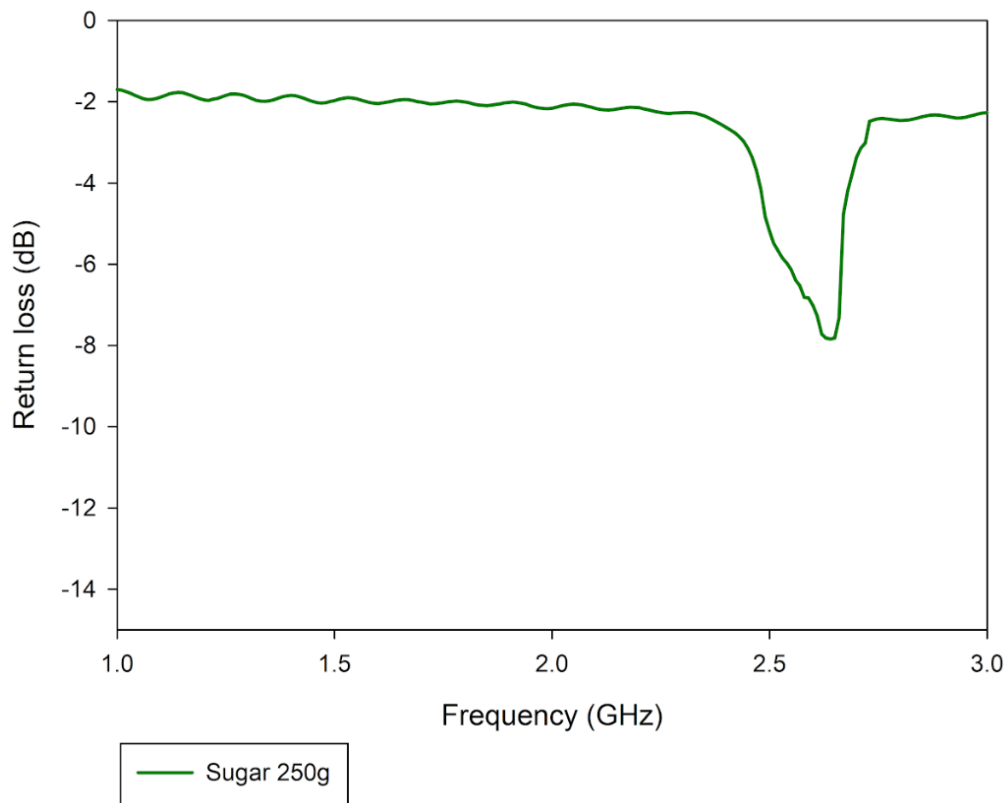


Figure 4.27: Reflection coefficient result for 250 g of sugar

All resonant frequency for 50g, 100g, 150g, 200g and 250g has shifted to the right hand of the original frequency as shown in Figure 4.28. The rapid increase in resonant frequency is the same as that of salt solution. As already been mention, the same procedure is applied before any concentration of sugar is tested using the fabricated antenna. The antenna is calibrated until reaching a stable 2.50 GHz. On the other hand, the reflection coefficient is quite challenging to be maintained as the antenna is susceptible to the surrounding. This calibration is needed to avoid any uncertainty on the VNA's result.

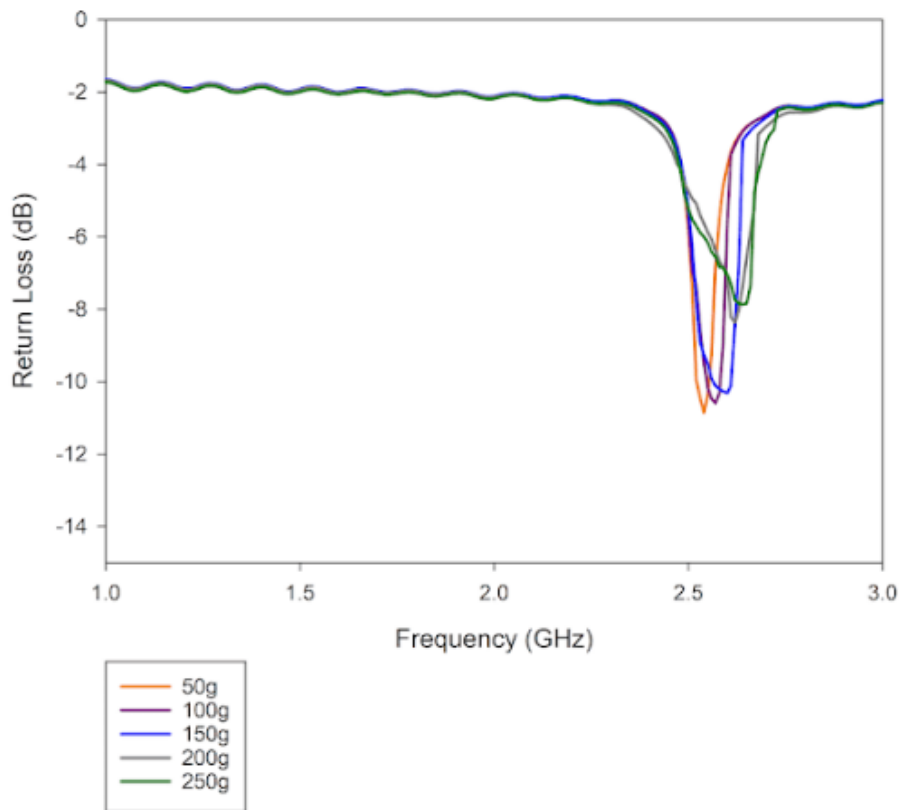


Figure 4.28: Comparison of the resonant frequency and reflection coefficient obtained for sugar solution

The location of the shifted resonant frequency plays a remarkable role in determining the level of sugar concentration and by looking to the result, high concentration causing the resonant frequency to be shifted more further from the radiated frequency.

Just as salt solution, when the antenna is exposed to the sugar solution, the original reflection coefficient changed. Therefore, the resonant frequency needs to change its position to suit the new reflection coefficient. The shifting is needed as the resonance resistance blocks the radiation. Increasing the level of concentration of sugar cause the resonant frequency to shift further as the resonance resistance is accumulated along with the increment of the reflection coefficient.

The shift in resonant frequency can be attributed to several factors related to the interaction between the sugar solution and the antenna. Here are some possible reasons:

Dielectric Properties: Sugar solutions have different dielectric properties compared to pure water. As the concentration of sugar increases, the dielectric constant of the solution changes, which affects the resonant frequency of the antenna. Higher concentrations of sugar increase the dielectric constant, causing the resonant frequency to shift.

Conductivity: The presence of sugar in the solution can also affect its conductivity. Changes in conductivity can influence the electromagnetic properties of the solution, leading to a shift in the resonant frequency.

Reflection Coefficient: As mentioned, the reflection coefficient changes when the antenna is exposed to the sugar solution. This change requires the resonant frequency to adjust to maintain proper impedance matching. Higher sugar concentrations result in greater changes in the reflection coefficient, causing a more significant shift in the resonant frequency.

Resonance Resistance: The resonance resistance increases with higher sugar concentrations, which can block the radiation and necessitate a shift in the resonant frequency to accommodate the new conditions.

Environmental Sensitivity: The antenna's sensitivity to its surroundings can also play a role. Any slight changes in the environment, such as temperature or humidity, can affect the antenna's performance and contribute to the observed frequency shift.

These factors combined explain why the resonant frequency shifts to the right as the concentration of sugar increases

4.5.4 Summary of Comparison of Salt and Sugar Solution

The resonant frequency for both solutions is shifted in accordance with the effect of impurities towards the dielectric properties of a pure solution. Both solutions are shifted to the right side of the radiated signal, which is 2.50 GHz. The level of the concentration of impurities affects the distance of the shifting.

Whereas for the reflection coefficient, the higher the level of concentration, the more power is being reflected and reaching 0 dB. When the concentration of salt and sugar solution increase, the reflection coefficient is increasing accordingly. The distortion on the original resonance resistance occurs as the antenna is exposed in a medium with a different dielectric property.

The higher the reflection coefficient, the higher the resonance resistance be. This is due to the changes in resonance resistance produces a new value of reflection coefficient. Therefore, to countermeasure the reflected signal due to the new resonance resistance, the resonant frequency shift from its original radiated frequency to fit in with the new reflection coefficient. The higher the reflection coefficient, the farther the shifting be, corresponds to the reflected signal.

The comparison of the simulated antenna and fabricated antenna is discussed to determine any uncertainties that contribute to any differences in resonant frequency. The targeted frequency is 2.45 GHz. Due to some human errors and instrumental errors, the radiated frequency of the fabricated antenna is 2.50 GHz. It has been set as the original frequency for comparison for each concentration of salt and sugar.

Next, the result for salt and sugar is presented in the form of a graph. The result includes the final position of the resonant frequency and the reflection coefficient. Different concentration produces its unique result using VNA. Before any solution is tested, precaution has been taken to ensure the result is valid. This is done by verifying the resonant frequency of the antenna to be at 2.60 GHz.

After that, the analysis for every salt and sugar solution is made based on the result from the VNA. Both salt and sugar solution has caused the resonant frequency to shift. Most shifting is to the right side of the original radiated frequency. Other than that, some factors are affecting the outcome of the reflection coefficient.

4.5.5 Analysis on Detection of Chloramphenicol in Seafood Product

Chloramphenicol is a broad-spectrum antibiotic that has been widely used in veterinary medicine for the treatment of various infections in animals. However, its use in food-producing animals is strictly regulated due to potential health risks to consumers. This analysis focuses on the detection of chloramphenicol residues in seafood products, exploring various analytical methods, regulations, challenges, and emerging techniques in this field.

As mentioned in Chapter 3, for this analysis, a total of five samples with different concentrations chloramphenicol and shrimps prepared to be used in this research. The chloramphenicol is mixed with water to make solution for the shrimps. Five containers denoted as containers C1, C2, C3, C4 and C5. Each container has a different weight of chloramphenicol in millilitres (mL).

For container C1, only 50mL of chloramphenicol mixed with water. Container C2, C3, C4 and C5 has a weight of 100mL, 150mL, 200mL, and 250mL of chloramphenicol,

respectively. Each number of chloramphenicol indicates a different level of concentration. 50mL indicates low concentration, 150mL of chloramphenicol represent medium concentration and lastly, 250mL signify high concentration.

For 50 mL of Chloramphenicol, the resonant frequency is shifting more further to the left as the iteration increases. The return losses also increase as the iteration increases. The result from the VNA is as in Figure 4.29.

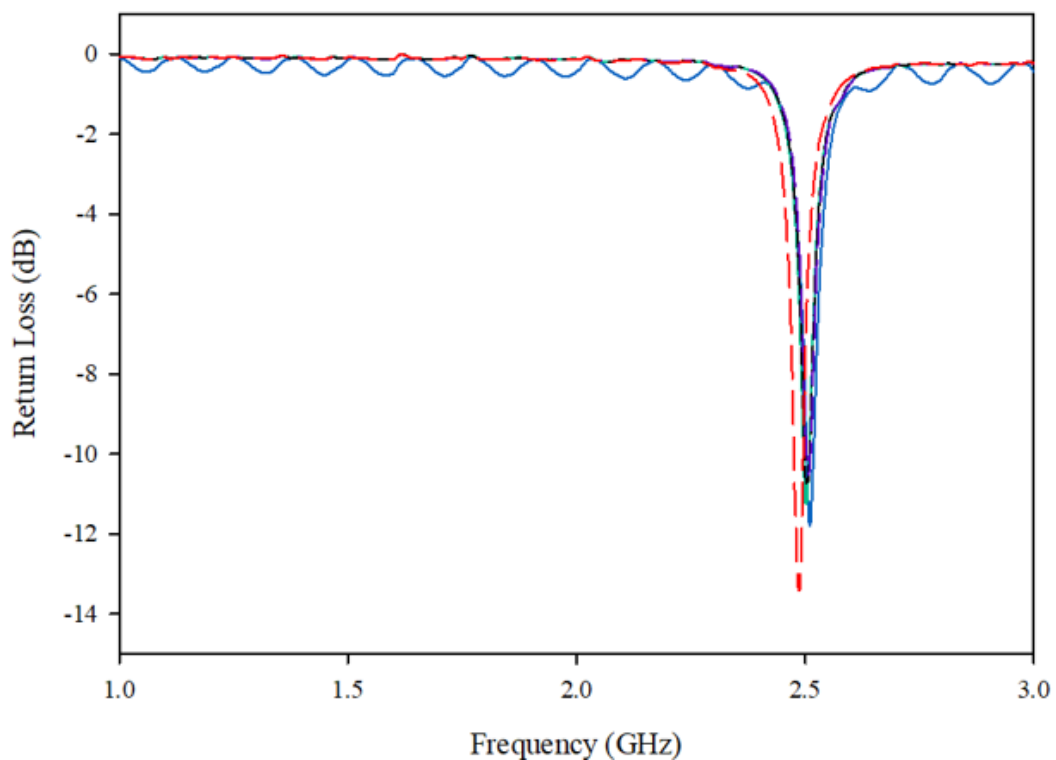


Figure 4.29: Analysis of 50mL chloramphenicol

For 100 mL of Chloramphenicol, with each iteration, the resonant frequency remains 2.5 GHz. As the number of iterations rises, the return losses decrease. As the number of iterations increases, the antenna's impedance matching may improve, leading to lower return

losses. This indicates that the antenna is better able to transmit power into the medium without significant reflection. The result from the VNA is as in Figure 4.30.

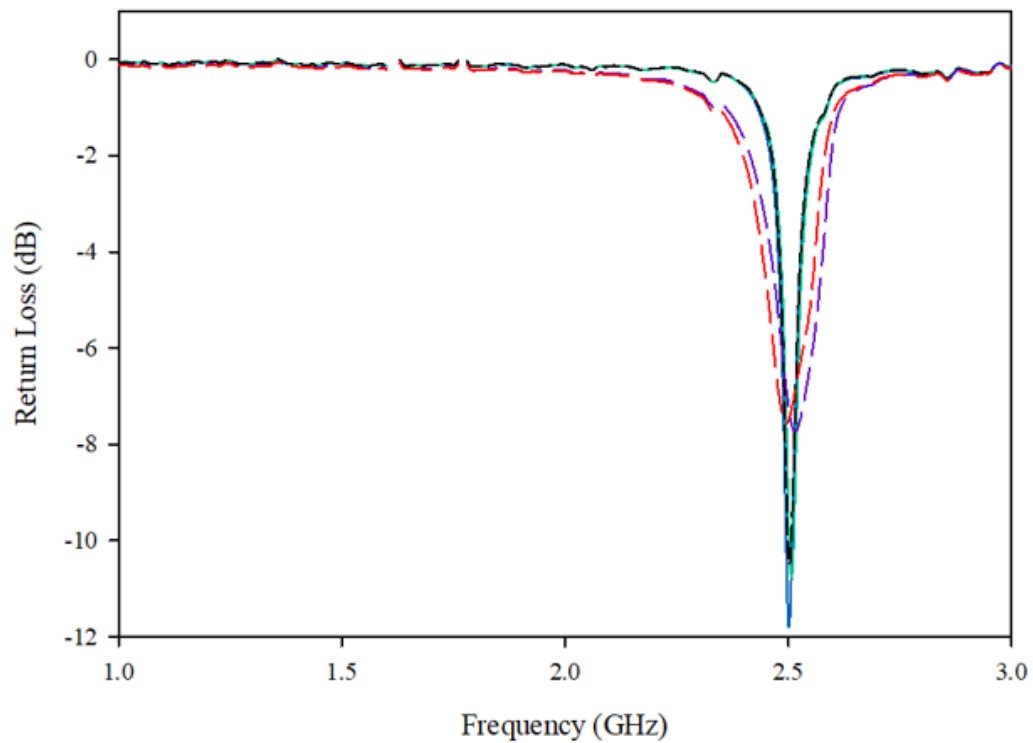


Figure 4.30: Analysis of 100mL chloramphenicol

Figure 4.31 shows the analysis for 150 mL of chloramphenicol. The analysis show that the frequency changed leftward from 1.91GHz to 1.5GHz. The return losses gradually reduce from -23 dB to -5 dB when iterations are increased. More iterations can lead to a more complex radiation pattern, which can optimize the antenna's performance, resulting in decreased return losses even if the resonant frequency remains unchanged.

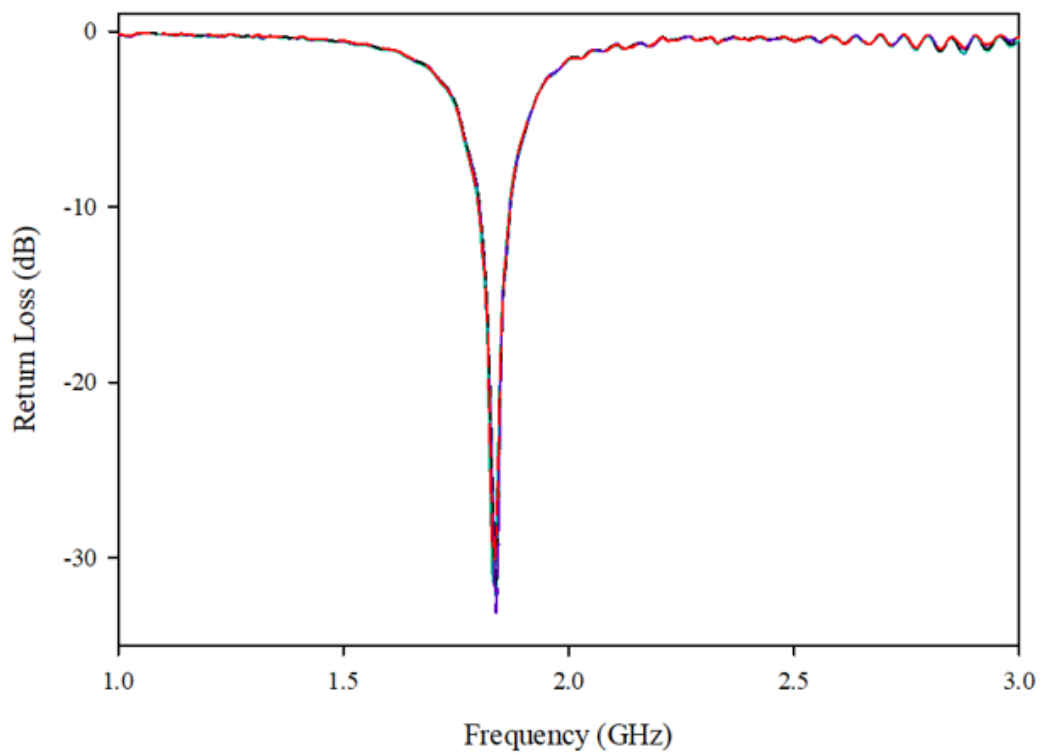


Figure 4.31: Analysis of 150mL chloramphenicol

Figure 4.32 shown the analysis for 200mL of chloramphenicol. The data shown that frequency shifting towards left from 1.91GHz to 1.5GHz. The return losses gradually decreasing from -23dB to -5dB as the iteration increases. The stability of the resonant frequency while demonstrating improved return loss performance with increased iterations.

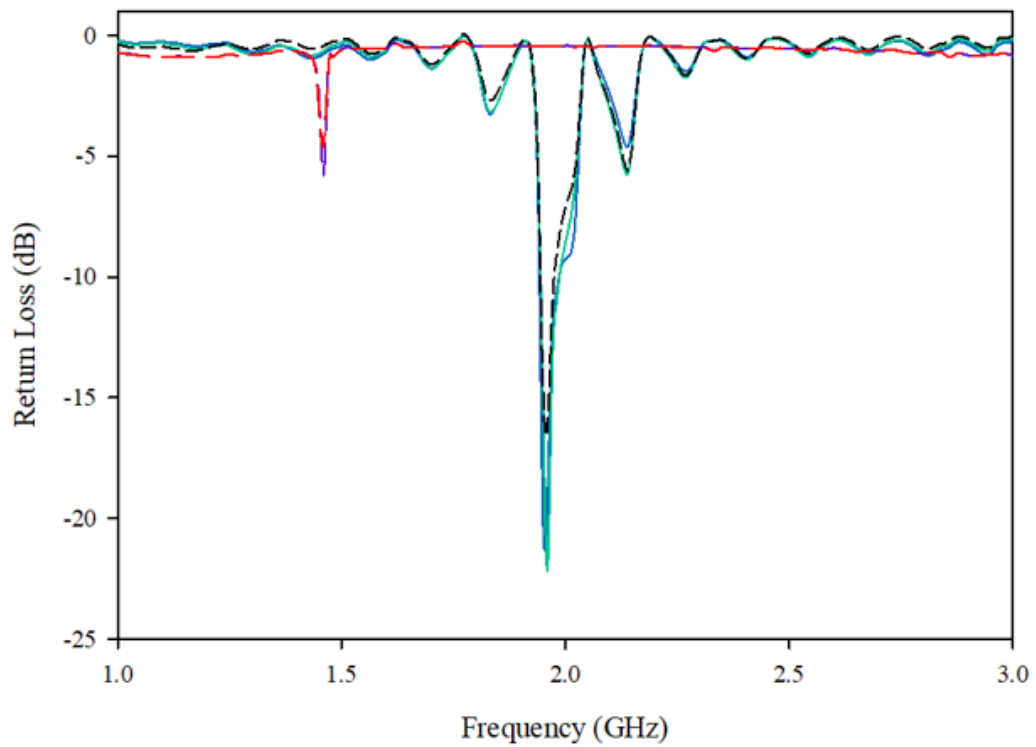


Figure 4.32: Analysis of 200mL chloramphenicol

The analysis for 250mL of chloramphenicol is presented in Figure 4.33. From the analysis, the frequency shifted from 1.5GHz to 1.48GHz in a leftward direction. As the number of iterations rises, the return losses gradually decrease from -9.81dB to -5.6dB.

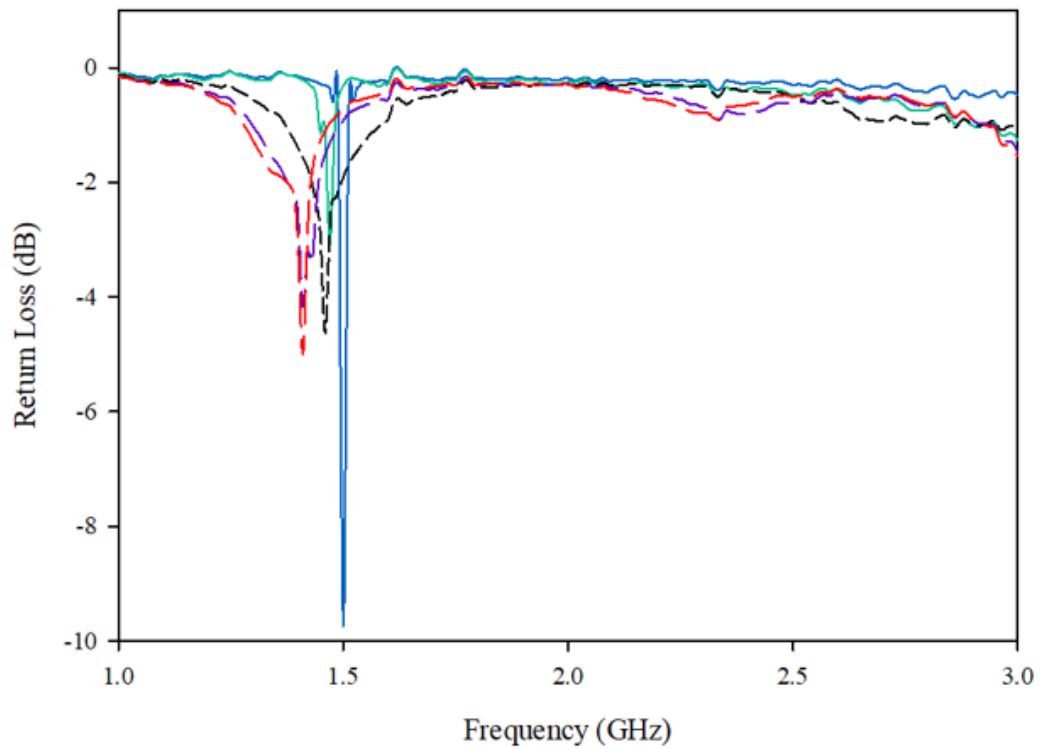


Figure 4.33: Analysis of 250mL chloramphenicol

4.5.5.1 Summary of Chloramphenicol on Seafood Product

The resonant frequency for chloramphenicol is shifted in accordance with the effect of impurities towards the dielectric properties of a chloramphenicol solution. Chloramphenicol solutions are shifted to the left side of the radiated signal, which is 2.50 GHz. The level of the concentration of impurities affects the distance of the shifting.

Whereas for the reflection coefficient, the higher the level of concentration, the more power is being reflected and reaching 0 dB. When the concentration of chloramphenicol solution increase, the reflection coefficient is increasing accordingly. The distortion on the original resonance resistance occurs as the antenna is exposed in a medium with a different dielectric property.

The shift in resonant frequency for chloramphenicol solutions can be explained by several factors related to the dielectric properties and the interaction of the solution with the antenna. Here's a summary and justification for the observed results:

The presence of impurities in chloramphenicol solutions affects their dielectric constant. As the concentration of impurities increases, the dielectric constant changes, causing the resonant frequency to shift. Higher concentrations of impurities typically result in a more significant shift to the left of the original frequency (2.50 GHz).

The reflection coefficient increases with the concentration of chloramphenicol, meaning more power is reflected back to the antenna. This is observed as the reflection coefficient approaches 0 dB at higher concentrations.

To maintain proper impedance matching, the resonant frequency must shift to accommodate the new reflection coefficient. This shift helps mitigate the reflected signal caused by the changes in resonance resistance.

Exposure to a medium with different dielectric properties distorts the original resonance resistance. As the resonance resistance increases with higher reflection coefficients, the resonant frequency shifts to match the new conditions. This shift is necessary to ensure the antenna operates efficiently despite the changes in the surrounding medium.

The shift in resonant frequency directly correlates with the level of impurities in the chloramphenicol solution. Higher impurity levels lead to greater shifts, indicating that the dielectric properties of the solution are significantly altered by the impurities.

The increase in the reflection coefficient with higher concentrations of chloramphenicol solutions necessitates a shift in the resonant frequency. This adjustment helps the antenna maintain its performance by compensating for the changes in resonance resistance.

The comparison with the Minkowski Fractal Antenna helps identify any uncertainties or differences in resonant frequency. The desired frequency range is 2.45 GHz, but due to human and technical errors, the constructed antenna's radiated frequency is 2.50 GHz. This initial frequency serves as a baseline for comparing the shifts caused by different chloramphenicol solutions.

In summary, the shift in resonant frequency is primarily due to changes in the dielectric properties of the chloramphenicol solution, influenced by the concentration of impurities. The reflection coefficient and resonance resistance also play crucial roles in determining the extent of the frequency shift.

The resonance resistance greater the higher the reflection coefficient. This results in a new value for the reflection coefficient as a result of variations in resonance resistance. As a result, the resonant frequency shifts from its initial radiated frequency to match in with the new reflection coefficient in order to mitigate the reflected signal caused by the new resonance resistance. The shifting correlate to the reflected signal and greater the higher the reflection coefficient.

The comparison of the Minkowski Fractal Antenna is discussed to determine any uncertainties that contribute to any differences in resonant frequency. 2.45 GHz is the desired frequency range. The constructed antenna's radiated frequency is 2.50 GHz as a result of some human and technical faults. It has been selected as the initial comparison frequency for each chloramphenicol solutions.

After that, the analysis for every salt and sugar solution is made based on the result from the VNA. Both salt and sugar solution has caused the resonant frequency to shift. Most shifting is to the left side of the original radiated frequency. Other than that, some factors are affecting the outcome of the reflection coefficient.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

In summary, this project successfully achieved its objectives, including the design, simulation, and fabrication of four iterations of a Minkowski Fractal as a resonator.

Using Computer Simulation Technology (CST) tools, we examined the variations of the Minkowski Fractal Antenna under a microstrip line. The optimal design was identified, resulting in the lowest return loss among the tested configurations.

A key aspect of selecting a microstrip patch antenna lies in its design. This study explored how variations in size impact both antennas gain and return loss. By designing the microstrip patch antenna with different iterations of the fractal, we aimed to reduce size while achieving the lowest return loss and highest antenna gain. Notably, the frequency shifting performed better than return loss and antenna gain, indicating that the current beneath the microstrip line is perturbed more effectively than the current under the patch.

This study successfully achieved its objectives by designing, simulating, and fabricating four iterations of the Minkowski Fractal antenna. While the simulation results demonstrated promising performance metrics, significant differences were observed between the simulated radiation patterns and the actual measurement results.

The simulations indicated optimal performance characteristics, such as lower return loss and higher gain, which are essential for effective antenna functionality. However, the measured radiation patterns exhibited discrepancies, suggesting that the real-world conditions

and manufacturing variances impacted the antenna's performance. Factors such as material imperfections, variations in the fabrication process, and environmental influences likely contributed to these differences.

The implications of these discrepancies are crucial for real-world applications. While simulations provide a valuable framework for antenna design, they may not fully account for the complexities encountered in practical settings. For instance, the variations in the measured return loss suggest that the antenna may not achieve the same level of efficiency as predicted in simulations, potentially affecting its ability to transmit and receive signals effectively in dynamic environments.

Furthermore, the differences in radiation patterns highlight the importance of robust testing and validation processes. These findings emphasize the need for careful calibration and adjustments during the fabrication process to minimize deviations between simulated and actual performance. Understanding these gaps can lead to improvements in future designs and manufacturing techniques, ensuring that antennas not only perform well in theory but also meet the rigorous demands of real-world applications.

Overall, while the Minkowski Fractal antenna shows great potential for enhancing performance in specific applications, the observed differences between simulation and measurement underscore the importance of thorough testing and optimization. Continued research and refinement are necessary to bridge the gap between theoretical models and practical implementations, thereby maximizing the antenna's effectiveness in real-world scenarios.

5.2 Recommendations

For future consideration, in order to improve the performance of microstrip patch antenna for seafood detection), there is a few suggestions:

- i. Different configurations of Minkowski Fractal Antenna to improve the performance of the antenna. Investigating alternative configurations of the Minkowski Fractal Antenna can yield significant improvements in performance. By experimenting with various fractal iterations, scaling factors, and geometrical arrangements, it may be possible to enhance parameters such as gain, bandwidth, and impedance matching. Each configuration can be optimized for specific applications, potentially leading to better sensitivity and accuracy in detecting impurities or contaminants in seafood products. Additionally, exploring other fractal designs, such as Sierpinski or Koch snowflake antennas, may also provide beneficial performance characteristics.
- ii. Modified the same design to be worked at higher frequency. Adapting the existing Minkowski Fractal Antenna design to operate at higher frequencies could enhance its resolution and sensitivity. Higher-frequency antennas typically exhibit smaller wavelengths, which can improve the ability to detect finer details in the dielectric properties of seafood products. This adjustment may involve optimizing the antenna dimensions and materials to ensure effective operation at elevated frequencies, thus allowing for more precise measurements and better differentiation of various contaminants.
- iii. The seafood detection process for microwave imaging system should be performed to understand the strength of the fabricated antenna. Integrating the

microstrip patch antenna into a microwave imaging system can provide a comprehensive understanding of the antenna's performance in real-world seafood detection scenarios. This approach would involve assessing the strength and clarity of the signals received from the fabricated antenna when applied in a controlled environment. By mapping the dielectric properties of seafood products through microwave imaging, researchers can gain insights into how different contaminants affect these properties, ultimately leading to improved detection methods. Additionally, this process could help in refining the antenna's design based on empirical data from real-world applications.

By pursuing these avenues for improvement, future research can significantly enhance the efficacy of microstrip patch antennas in seafood detection. Adapting configurations, operating frequencies, and integrating advanced imaging techniques not only improve antenna performance but also expand the potential applications in food safety and quality assurance.

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APPENDICES

Appendix: Journal Publications

1. **Samat, A. A.**, Zaidel, D. N. K. A., Mat, D. A. A., Sharip, M. R. M., Zaidel, D. N. A., Muhamad, I. I., & Then, Y. L. (2020). Surface current distribution and performance analysis of different feeding techniques for microstrip patch antenna. *2020 13th International UNIMAS Engineering Conference (EnCon)*, 1–5. <https://doi.org/10.1109/encon51501.2020.9299340>
2. **Samat, A. A.**, Zaidel, D. N. A., Anwar, R., Sahidi, M. M. M., Mat, D. A. A., & Sharip, M. R. M. (2025). Effect of bending condition towards the performance of Pac-Man textile antenna. *Journal of Advanced Research in Applied Sciences and Engineering Technology* - Accepted for Publication