Food Quality Inspection using Microwave Non-Destructive

Techniques.

Group # 06

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ELE 491–Electrical Engineering Design Project II Report

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May 2022

Declaration of Authorship

I declare that this report is my own work and, to the best of my knowledge and belief, it does not contain material published or written by a third party, except where permission has been obtained and/or appropriately cited through full and accurate referencing.

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Acknowledgment

We would like to thank Dr. Mostafa Shabaan who was the ELE-490 course coordinator as he has helped immensely by explaining all the procedures needed such as writing reports and presentations as these documents help one explain their project to the public. Further, we would like to than Mr. Wasil El Tahir and Mr. Ibrahim Abu Saif as they were of great help to us while doing our project and supported us as much as they could with setting up the hardware components and purchasing the required components for our project. Last but not least, we would also like to thank Dr. Amer Zakaria and Dr. Naser Qaddoumi who were our advisors for this project and have helped us understand more about the applications of electromagnetic radiations. They have helped us understand our project by conducting weekly meetings and giving us small tasks to do for the following meeting. These meetings have been extremely useful in picking the best possible approach for this project.

Abstract

Cold Cuts are processed meats that undergo several stages of processing and storage which potentially exposes them to various unwanted microbial organisms. Some of the factors that affect cold cuts could be the water level of the cold cut and the pH level as these are some of the building blocks of microbial growth. Since cold-cuts are consumed by almost everyone and the chance of cross contamination of freshly cut cold-cuts is high; one should look at finding a way to be able to detect the quality of the cold-cuts by a device that is small enough to be handheld and cheap enough so all supermarkets could have. With this goal in mind, we plan on building a device that will be able to tell the end-user whether the cold cut that they plan on purchasing is safe to consume. Our device will use Microwave Non-destructive waves produced by a Gunn Oscillator followed by patch antennas to send and receive these waves as well as a microprocessor that will process the data and figure out whether the cold cut is safe to consume or not.

Keywords: ***microwave, non-destructive testing, food inspection, cold cuts, reflection coefficient, food spoilage, dielectric measurements.***

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Chapter 1 . Introduction

In this chapter, we provide a short introduction to topic. Then, we address the challenges and objectives. Finally, the general organization of the report is presented.

1.1. Overview

Cold cuts are pre-cooked or cured meats that undergo several stages of processing and storage. Bacteria and various unwanted microbial organisms associated with refrigerated cold cuts cause spoilage and unpleasant defects such as sour off-flavors, discoloration, change in the fat content along with the PH value, and slime production. The spoilage of cold cuts could occur at different stages such as packaging and serving operations, from hands (especially in the case of inadequate hygiene), transportation, slicing machines, and storage time. As mentioned, many sources and stages can influence spoilage and prepare a suitable environment for microbial contamination into cold cuts, hence acquiring microbial spoilage over time. As such, cold-cuts and meat products generally need an inspection system for cold-cuts quality monitoring and detecting microbial spoilage.

1.2. Problem Statement

Design a portable microwave non-destructive testing system to evaluate whether a Cold cut is spoiled or not.

1.3. The Need

Food security is having reliable access to adequate, affordable, nutritious food to meet an individual's dietary needs. Food security is required to ensure that everyone has access to safe and healthy food at all times of the year. Because of the consumption of contaminated food, around 600 million people fell ill worldwide; and 420,000 die every year. In 2004, 160 countries voted at the United Nations to make safe food a human right rather than a commodity. However, there are many challenges due to the strains put on the supply chains [1]. The cost of unsafe food is high as the United States Department of Agriculture (USDA) estimates that foodborne illnesses cost the United States (US) at least $15.6 billion annually in lost productivity and medical care [1]. Therefore, a system is needed for the monitoring of food to enhance safety management and food quantity.

This project aims to target supermarkets, as they do not adhere to similar strict regulations as factories, thus they provide perfect conditions for contamination and spoilage. To demonstrate, a study that was comparing the detection of Salmonella in chicken meat between supermarkets and wet markets in Mexico concluded that out of 1160 chicken meat samples collected between 2016 and 2018, 27.2% of the supermarket chicken had Salmonella compared to 9.0% in wet markets [2]. Furthermore, a study conducted by researchers of the University of Adelaide, Australia examined the 174 Cold cut sample from different supermarkets [3]. The samples were tested for the presence of common types of microbial contaminants, and the results indicated that “134 (77%) had bacterial levels that failed to meet food standards guidelines” [3]. This shows that at the last stage of the supply chain, contaminations can be detected at a high rate due to not adhering to the necessary food safety regulations. Thus, we conclude that in our research we should focus on building a device that can be used to detect the overall quality of cold cuts sold in supermarkets instead of building a system that focuses on checking the food quality at factories.

This project will be mainly focusing on cold cuts as they are high-risk foods that are typically ready-to-eat meats. According to a study conducted by the Centers for Disease Control and Prevention (CDC) in the US, 1 in every 6 supermarkets kept cold cuts in warm temperatures, thus creating a perfect environment for microbial activity and spoilage [4]. Further, about half of the supermarkets that were in the study did not clean the slicers used every 4 hours. This indicates that even if there was only one contaminated piece of cold cut, any other cold cut piece sliced using the same slicer would be contaminated as well [4]. Lastly, it has been noted that cold cuts provide a perfect growth environment for types of bacteria such as listeria which have a relatively high mortality rate.

1.4. Project Objectives

The objective of this project is to design and prototype a noninvasive device that will improve foodspoilage detection methods to ensure food safety and security. The system will depend on electromagnetic sensing spoilage and contamination of food products, specifically cold-cut meat products. The microwave detection system will utilize antennas to measure parameters related to the dielectric properties of the cold cuts. The presence of spoilage alters the dielectric properties that will be monitored using microwave measurement systems. The system will provide quantitative and/or qualitative assessments of the samples' conditions.

The objective tree of the proposed system found below shows the importance of each category and their respective subcategories when compared to each other. This essentially explains how important some of the factors are and the amount of time we plan on spending to meet the current expectations set.

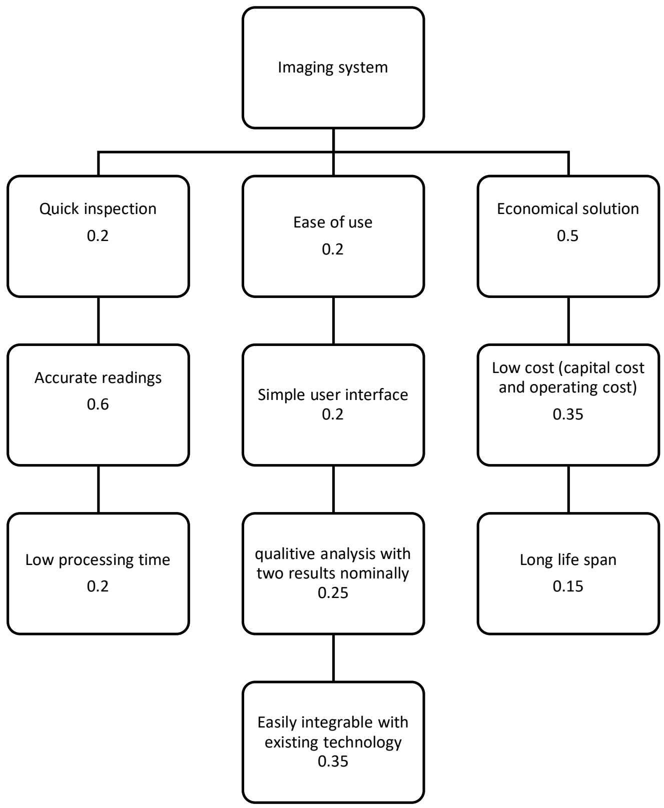

Figure 1.1: The Objective Tree of the System.

1.5. Report organization

The report is divided into multiple chapters and all the chapters have sub-sections. This report essentially begins by explaining the importance of the project by using statistical data to explain the premise. It follows with defining the objectives that we plan on achieving at the end of the project.

In Chapter 2, the report has all the background on the various techniques that could be used to achieve the end goal. It starts by explaining what Microwave Non-Destructive testing is and then shows some of the advantages of using Microwave Non-Destructive Testing. It is then followed by showing some of the other techniques that one would use to tackle the situation on hand. Finally, the chapter ends with picking the technique that we plan on using as its advantages are more suited for this project.

In Chapter 3, the report looks at all the Engineering Requirements and its Marketing Requirements that we need to achieve the best results. The chapter ends with showing the Engineering Requirements Trade-off Matrix.

In Chapter 4, we focus on explaining our proposed solution and explaining the design procedure that we shall use to achieve our end goal. The chapter ends with explaining the budget needed to complete the project and by showing the prices of all the components needed to build our prototype.

In chapter 5, we focus on explaining the results and limitations of the study we performed, and the initial measurements performed to identify the design parameters, such as the operating frequency, of the inspection system.

In the last chapter, we end the report with a conclusion and explaining some of the work that we shall do in the following semester. At the end of the chapter, we show a detailed work plan explaining all the steps that we will need to finish and the approximate time that we shall need to complete the task at hand.

Chapter 2 . Background

In this chapter, we will discuss the fundamentals, possible and current solutions, and literature review of the project to explain some of the reasons why we chose the proposed design.

2.1. Background on Microwave Non-Destructive Testing

Microwave non-destructive testing is an application of electromagnetic radiation which involves the use of electromagnetic waves ranging from 300 MHz – 300 GHz to perform various types of non-invasive and non-destructive tests of materials such as food products to examine a property ofthe test subject and deduce information about its condition [5]. It is classified as either far-field sensing or near-field sensing according to the distance of the test subject from the microwave antenna(s). A typical microwave testing system is composed of an electromagnetic radiation source, one or several transmitter antennae, a receiver system that utilizes antenna(s) to receive the backscattered and forward transmitted waves, and lastly the processing unit that utilizes algorithms to obtain information from the received signals [6]. For this senior design project, we plan on using this non-destructive and non-invasive technique to find impurities and contaminants in food products that are harmful to consume.

One of the applications of microwave imaging is product inspection in food quality management. "Food quality involves the quality characteristics of food that are acceptable to consumers, including such external factors as appearance (size, shape, color, gloss, and consistency), texture, and flavor" [7]. This is a critical application as microwave imaging provides a non-destructive and non-ionizing imaging technique to check for contamination in food products. Using such a technique can help in detecting contaminations which can be found as physical hazards such as plastics, glasses, and tiny bones, chemical hazards such as mold and herbicides, or microbial organisms which can invade products throughout any of the manufacturing stages. The imaging techniques used for food quality management can be classified into on-line techniques (directly on the production line) and off-line techniques (at laboratories) [8]. Off-line food testing techniques are quality of the remaining products can only be approximated using the test results, and their condition remains uncertain.

Table 2.1.1: summarized information about food non-destructive testing techniques [11][12][13][14][15][16][17].

Imaging Technique	**Brief description**	**General Application/s**	**Advantage/s**	**Disadvantage/s**
Hyperspectral Imaging (HSI)	HSI works by exposing products to an EM wave and then processing the backscattered wave. The emission spectra of the product can then be extracted through mathematical manipulation [11].	Aerospace, Agriculture, Astronomy, Medicine, and Military Industries	Powerful analytical tool for rapid, non-contact and non-destructive food quality assessment	Complex image processing; requires skilled personnel. Expensive
Electrochemical impedance spectroscopy (EIS)	Exposes the product of interest to varying frequencies of electrical signals using electrodes to generate an impedance function relative to the product's frequency response and an equivalent circuit model [13].	Food inspection (can be used for solids, liquids, or semi-liquids) [14]	Mainly utilizes low frequencies which results in low resolutions [14]	Complex computations, not as accurate as other methods [14]. Hard to use with products such as grains.
Nuclear magnetic resonance (NMR)	NMR is based on how electromagnetic radiation is absorbed by atoms. It is done by applying a strong magnetic field in which RF signals of different frequencies are applied to the product in a short pulse [11].	Food Quality and Safety	precise	expensive and time consuming.

Microwave imaging	Utilizes EM microwaves which exploit the local dielectric properties of the product to produce an image.	Biomedical applications, industrial testing, security detection	Easy to implement with no use of ionizing radiation and mechanic sound waves.	Sensitive to “opaque” conductive packaging that does not allow EM waves to penetrate.
Raman imaging	Raman imaging is used to generate both spatial and spectra information which is processed to identify the type of chemical components present [12]	Food Products, Industrial and Biological Analysis	High resolutions providing in-depth details of the sample	Expensive and lack of efficient substrates and time consuming
X-Ray imaging	Utilizes X-rays to produce a grey-scale image depicting the foods interior. Contaminations mostly have different contrast compared to the food product [13].	Medicine, Food Science, and Agriculture	Cheap and simple to use; produces 3D information that can be manipulated numerically	Cannot detect low density contaminants e.g., hair, paper, plastics
ultrasound imaging	Uses a set of ultrasound transducers to generate ultrasound waves to enable the measurement of the size, shape, composition, structure, and movement of food particles in a food product [11].	Medical Technology, Agricultural and Food Products Quality Assessment, and Packaging	Easy, cheap and without complicated post-image processing	Dependent on the amount of energy reflected through materials

fluorescence imaging	This technique utilizes the fluorescence of molecules when exposed to specific EM waves. UV or visible light are commonly used [11].	Biological, Microbial, Food Quality and Safety	Can detect minute contaminants	Possess limitations since not all materials can be excited by fluorescence.
RFID sensors	Utilizes RFID tags for physical, chemical, and biological sensing. This is done by measuring the resonance impedance spectrum of the tag's antenna [15]	FOOD inspection	self-calibration and -correction for different environments[g]. Low cost. Can use chip less & battery less sensors.	Requires complex analysis and has hysteresis issues [16].

2.2. Available solutions

2.2.1 Near-Infrared Imaging and Spectroscopy

Near-infrared (NIR) spectroscopy is a non-destructive technique that is based on the absorption of electromagnetic radiation and the use of infrared light to analyze materials and products. It is used widely in many applications ranging to chemical analysis, food and agriculture products, and pharmaceutical raw materials. NIR region covers a wavelength in the range 780 to 2,500 nm along with photon energy in the range of 2.65×10^{-19} J to 7.96×10^{-20} J. Furthermore, NIR can be used in meat analysis and evaluate meat quality through the detection and quantification of marbling (white fat streaks), measure the content of fat and other compositional parameters, and detect adulterations and spoilage. NIR technique uses different chemometric and machine learning approaches to extract the relevant information from the spectra, hence monitoring the quality of meat. Different approaches such as Random Subspace Discriminant Ensemble, Principal Component Analysis, Partial Least Squares, Artificial Neural Network, Linear Discriminant Analysis, Support Vector Machine, and other approaches could be used concerning meat analysis. NIR is a reliable tool that uses machine learning algorithms for monitoring meat quality and improving safety management [9].

The main advantages of NIR technique are that it is rapid, non-destructive, enables preliminary monitoring of different types of food, intuitive, and easy-to-use software interface. On the other hand, NIR has some disadvantages such as not all compounds absorbing infrared light, hence NIR technique can't be utilized with such systems. Also, NIR devices, especially the benched instruments, are relatively expensive compared to other techniques [9].

2.2.2 Resonant-Circuit Sensors

The LC resonator circuit sensor is another non-destructive technique used to monitor bacteria growth and analyze meat and dairy products quality. The sensor measures the complex permittivity of the biological medium using an antenna. In general, when the meat is exposed to bacteria growth, contamination will occur, hence the complex permittivity will increase. Furthermore, the sensor consists of an interdigital capacitor connected in series to a spiral inductor printed on a thin plastic or paper substrate, an antenna, and an impedance detection device. The impedance detection device is needed to measure the impedance across the terminals of the antenna. Then, an impedance spectrum is generated to measure two parameters: fo and fz. These two parameters will be used to calculate the complex permittivity of the medium and find a correlation between bacteria growth and the complex permittivity, hence monitoring meat quality [10].

The main advantages of the LC resonator sensor are fast, cheap, and non-destructive. However, the limitations of the sensor are the effect of temperature, the effect of sensor location, and the effect of liquid absorption. The substrate has a different temperature coefficient, which has a significant impact on the response of the sensor. Also, the frequency response of the sensor experiences some frequency shifting when the location and the orientation of the sensor vary, hence affecting the complex permittivity of the medium. Last, when the sensor is immersed in a liquid, the liquid might be absorbed into the polyurethane layer, decreasing f0 and fz and causing misleading measurements for the complex permittivity [10].

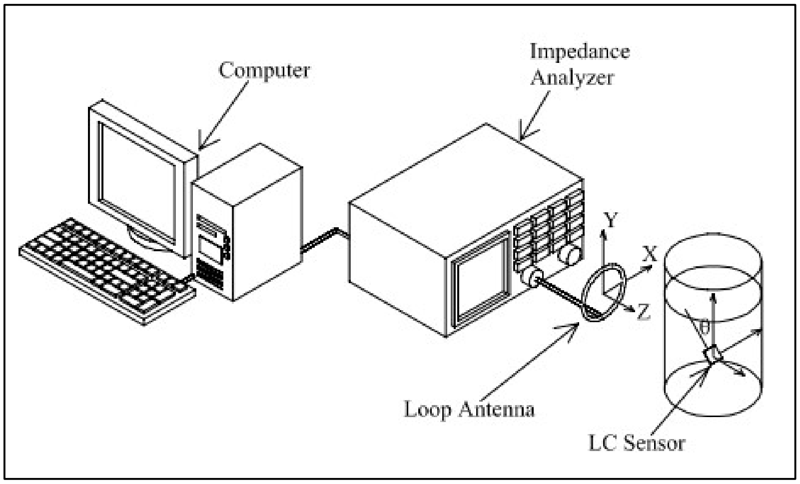

Figure 2.2.2: The system setup [10]

Chapter 3 . Engineering Requirements

In this chapter, we will discuss all the Engineering Requirements that need to be accomplished to make sure that the device can be used effectively.

3.1. Engineering Requirements

Performance

a. The system should have an accuracy of at least 90% of detecting spoiled food products.
b. The inspection time should not exceed 10 seconds.

Functionality

c. The system should utilize the change in the dielectric properties of spoiled foods to judge whether the food product being examined is good or bad.

Energy

d. The system should have a maximum power consumption less than of 50mW.

Health and Safety

e. The system should not expose humans to unhealthy levels of electromagnetic radiations by limiting the radiated output power to safe level.

Maintainability

f. The system should utilize commercial off the shelf components to ease maintenance

Operational

g. The system should use frequencies on ISM frequency bands other than that used for any commercial application such as Cellular networks to limit the interference it produces.

Usability

h. The user interface will be as simple as possible such that by pressing a button, the user is able get results indicating whether the examined food product is good or spoiled

3.2. Mapping of Engineering Requirements to Market Requirements

The Marketing Requirements are a critical aspect of the project as it shows some of the areas that we are planning on focusing as well as some of the benefits that we plan on achieving in this project. The Marketing Requirements need to be linked to the Engineering Requirements so that the Marketing requirements can be achieved under the constraints.

Marketing requirements:

1- The microwave-based inspection system should a high accuracy

2- The inspection time should be quick

3- The microwave-based inspection system should be user friendly and easy to operate

4- The microwave-based inspection system should be eco-friendly and economical

5- The microwave-based inspection system should be easy to integrate with existing infrastructure

6- The microwave-based inspection system should be safe to use

Marketing Requirements	**Engineering Requirements**	**Justification**
1,2	1- The system should have an accuracy of at least 90% of detecting spoiled food products. 2- The inspection time should fall between 5s – 10s.	As the system is expected to be deployed in a supermarket setting, the accuracy of readings should be as high as possible to limit wasted products and the total time taken for inspection should be minimized to limit the effects of the system on production speed
4	1- The system should have a maximum power consumption less than of 50mW.	As the microwave-based inspection system is expected to be operational for long instances of time, its power consumption should be made as low as possible without limiting the system's performance. A power consumption less than 50mW is already lower than most inspection system currently used throughout the food industry.
3	- The user interface will be as simple as possible such that by pressing a button, the user is able get results indicating whether the examined food product is good or spoiled.	As the system is going to be operated by supermarket workers, the user interface should be made as simple as possible such that minimal training is required to familiarize workers with the system's operation. The results should only indicate whether the food product examined is good or spoiled.
5,6	- The system should not expose humans to unhealthy levels of electromagnetic radiations by limiting the radiated output power to safe levels - The system should use frequencies other than that used for any commercial application such as WIFI or Cellular networks to limit the interference it produces.	Introducing the microwave-based inspection system to a supermarket setting should not affect the connection quality for any wireless device used there, and the interference generated by these devices should also not degrade the system's performance. In, addition the radiated power used for inspection should be below the risk level for

		humans as workers are expected to be exposed to the system daily.

Table 3.2: Mapping of Engineering Requirements to Market Requirements

3.3. Engineering Requirements Trade-off

Table 3.3: Engineering Requirements Trade-off

Legend: ↑: positive correlation; ↑↑ strong positive correlation, ↓ negative correlation, ↓↓ strong negative correlation.

		performance	**Interference generated**	**Power consumption**	**Reliability and Availability**	**Maintainability**	**cost**
		+	**-**	**-**	+	+	**-**
Performance	+		↑	↓↓	↑	↓	↓↓
Interference generated	-	↓		↑↑	↑		↑
Power consumption	-	↓↓	↑↑		↓	↑	↑
Reliability and Availability	+	↑	↑	↓		↓	↓
Maintainability	+	↓		↑	↓		↑↑
Cost	-	↓↓	↑	↑	↓	↑↑	

As shown above we can notice that the cost of the device has a negative correlation to the performance as it would better equipment or more antennas to get more data. We can also notice if the interference generated is high then the cost of the system will also increase as it would require better equipment to get rid of all the interference generated. Maintainability could decrease the cost of the device as the components are readily available in the market; this would imply that defective components will be easily replaced. All the above situations need to be understood to design a device with the least drawbacks and the best performance.

Chapter 4 . Proposed solution

In this chapter, we present the solution agreed upon for this project.

4.1. Description of the proposed solution

The proposed solution is the use of a microwave-based non-destructive inspection system for testing cold cuts. The inspection system will be a portable device that is targeted towards supermarkets. The inspection system will be operated using a battery as it is expected to have a low power consumption. A typical inspection would last from 10s-20s in which the transmitting and receiving patch antennas will be placed on the cold cut sample to extract information about its reflection coefficient. The results will then be displayed as a simple spoiled/non-spoiled message to the user.

4.2. Design procedure

To create the microwave-based inspection system, the first step will be to perform a study on the change of dielectric properties of cold cuts. Different samples of the same type of cold cut will be utilized and stored under different conditions. Their dielectric property will be measured using a vector network analyzer equipped with an open-ended coaxial probe at fixed positions periodically until visual signs of spoilage and odors can be noted. The test results will be used to quantify the expected dielectric constant of a spoiled cold cut and its reflection coefficient. The inspection system's operating frequency will be chosen according to the frequency that shows the greatest change in the reflection coefficient.

After collecting the results of the study, the inspection system would be designed. The first step in designing the inspection system is deciding on the system's operating frequency. This is done by creating a setup consisting of a radiofrequency source, antenna, circulator, envelope detector, and a voltmeter as shown in figure 4.2.1. The parameter being measured is the amount of power reflected by the cold cut sample as one antenna is used for transmitting and receiving electromagnetic radiation. The operating frequency is to be chosen based on the frequency at which the greatest percentage change happens between spoiled and non-spoiled samples.

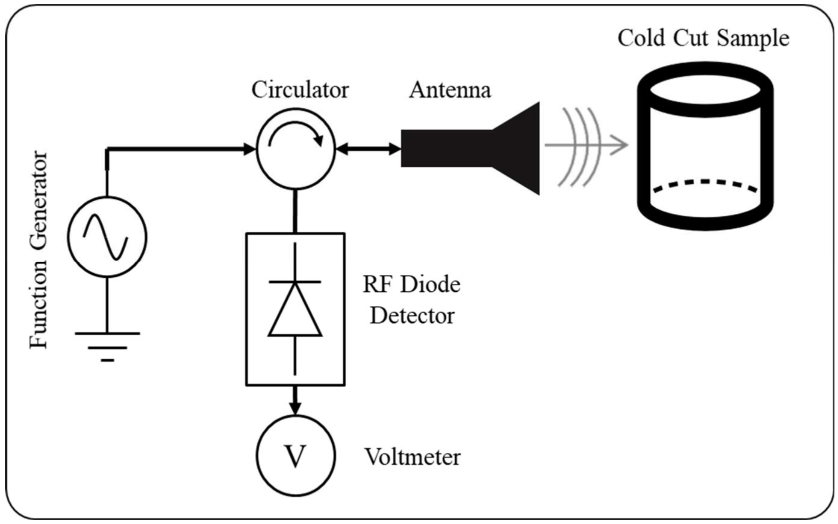

Figure 4.2.1. System Design Setup.

After deciding on the system's operating frequency, the first component of the microwave-based inspection system is the radiofrequency source which will be a Gunn oscillator that is biased to create an electromagnetic wave at the desired frequency with a controlled power level. A reference signal will be fed to the microcontroller utilized such that the incident wave power is saved for calculations. The electromagnetic wave will be radiated using an appropriate patch antenna that will be touching the cold cut sample. Receiving patch antennas will be placed near the transmitting antenna and behind the cold cut piece. The received electromagnetic waves will be translated into varying voltages by using a simple envelope detector such that the microcontroller's analog-to-digital converter can sample the amount of reflected and received waves.

As the inspection system is unable to measure the dielectric constant, the algorithm used would mainly utilize the reflection coefficient of the samples. the varying voltages that are sampled by the microcontroller will be used to approximate the reflection coefficient of the cold cut sample. The reflection coefficient is found by dividing the measured reflected wave magnitude by the incident wave magnitude obtained before. It is expected that a typical inspection would utilize 5s-10s of reflection coefficient data. Thus, the algorithm used will utilize 1-D data filters to clean the calculated reflection coefficient and the filtered output will be compared to a saved reflection coefficient profile. The results will be displayed accordingly on an LCD display to show the user whether the cold cut sample is spoiled or not as shown in the figure below.

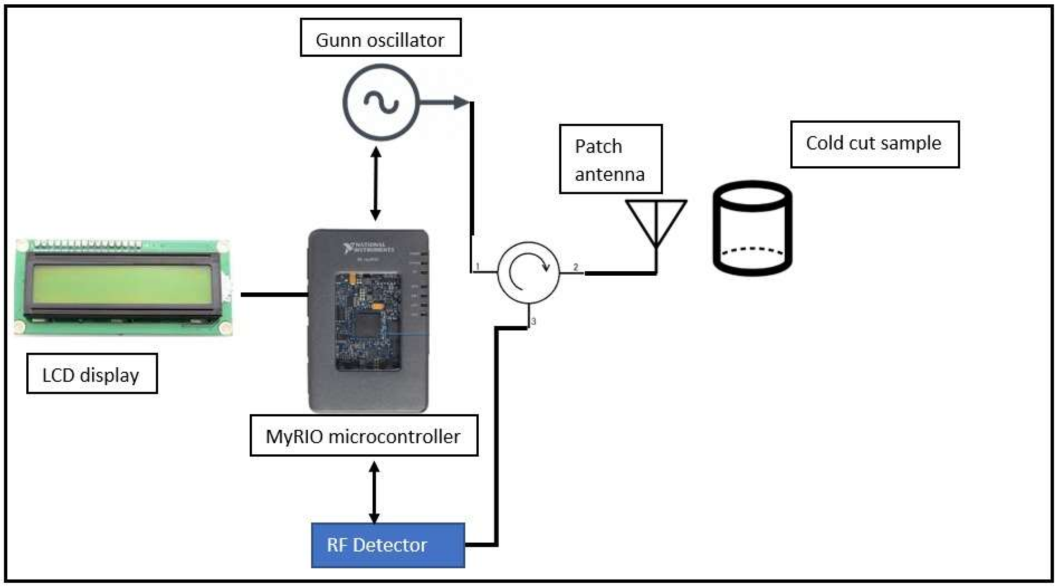

Figure 4.2.2. Modified System Diagram.

It must be noted that the temperature-influenced change in the reflection coefficient is not being considered here as we are assuming that the cold cut samples are at around the same temperatures as the ones used to create the algorithm. To solve this, we are planning to measure the reflection coefficients of samples at different standardized temperatures and if possible, add a temperature sensor to the inspection system. Further, to minimize the effect of interferences, we are considering the use of a shielding case that will be placed around the inspection system.

4.3. Budget and Cost Estimation

Item Description	Unit Price (AED)	Quantity	Total Price (AED)
Food Samples	100	10	1000
Antennas	250	4	1000
Connectors	100	10	1,000

Detector	1,000	1	1,000
Microprocessor (myRIO)	5,000	1	5,000
Gunn Oscillator	250	4	1,000
Total Costs	10,000		

Table 4.3: Budget and Cost Estimation

Budget justification

- **Food Samples:** They are going to be used to detect the change in the dielectric properties. Weplan on measuring these changes and be able to use the data obtained to build our device.
- **Antennas:** They are going to be used to transmit and receive the microwave signal that will be
  used to detect whether the food product is safe to consume.
- **Connectors:** They will be used to connect the ends of the cables that will operate in themicrowave spectrum.
- **Detector:** it will be used to convert microwave signal to a voltage output. This value will thenbe used to make the necessary analysis needed to determine the quality of food samples.
- **Microprocessor:** It will be used to control the device and make certain computations to determine whether the food sample tested is safe or not. The microprocessor will need to beprogrammed to make sure that all the parameters are being tested before generated a result.
- **Gunn Diode Oscillator:** It will be used to generate the microwave energy that will be neededto take certain images which will help determine whether the food product is safe to consume.

4.4. Testing Procedure

Tests to be performed:

1. To test the microwave-based inspection system performance, a specified number of inspections will be performed on a cold cut to determine the accuracy of the system and the average inspection time. (Engineering Requirements: a, b)
2. To test the functionality of the microwave-based inspection system, samples of spoiled and non-spoiled cold cuts will be utilized. Electrical field strength measurements will be taken on both types to validate the existence of a significant change in the dielectric constant of cold cuts as the dielectric constant controls how the cold cut sample interacts with microwaves. An approach that can be used is to measure the reflection coefficient of samples from the same manufacturer, uniformly sized, and from the same production batch. The samples would then be divided into 3 batches with the first batch being stored at room temperature, the second batch refrigerated at around 4°C, and the last batch would be stored in a freezer at under 0°C. The electric field strength measurements will be taken periodically for 10 days to express the change in electric field strength relative to storage time and spoilage. (Engineering Requirements: c, g, h, f)
3. To test the power consumption of the microwave-based inspection system, a power meter will be connected to monitor the power consumption of the system for a set period, the average power consumption will be used to estimate the typical power consumption of the system. (Engineering Requirements d, e)
4. The maximum expected radiation levels of the RF source utilized in the microwave-based inspection system will be measured to check whether they comply with IEEE C95.1-2019 (IEEE Standard for Safety Levels with Respect to Human Exposure to Electric, Magnetic, and Electromagnetic Fields, 0 Hz to 300 GHz). (Engineering Requirements: g, f)
5. To test the reliability of the system, the system will be operated continuously for 20+ hours multiple times to verify whether the system can operate for long periods of times or not. (Engineering Requirements: i)

Chapter 5. Preliminary Results and Discussion

This chapter aims to discuss the findings of both phases of the project. This project was divided into two phases where the first phase focused on finding the dielectric constant (ε') and loss factor (ε'') of both the chicken and beef samples at different frequencies. Then using that data, build a proposed system. The results obtained from the system are discussed in this chapter.

5.1 Dielectric Measurements Study Results

The first phase of our senior design project was to perform a study to investigate the effect of different factors on the dielectric properties of cold cuts. Factors including temperature, aging (long-term storage), and unhygienic surface (that may expose the meat/chicken samples to bacteria) may cause a significant change in the dielectric properties of cold cuts. It was significant to perform such a study due to the limited resources on the dielectric measurements of cold cuts. Therefore, we aimed to verify the influence of different factors on the dielectric properties as time passes. Furthermore, the dielectric properties, consisting of the dielectric constant (ε') and loss factor (ε''), are expressed as $\varepsilon = \varepsilon'$ a$-$ j ε''. The dielectric constant is described by the capacity for energy storage in the electric field in cold cuts. It is also associated with the amount of electromagnetic energy reflected or transmitted into the samples. The dielectric loss factor describes how well a material absorbs energy from electric fields and converts that energy into heat. Both properties are influenced by the temperature, freshness of the samples, food composition, and the density of the samples.

We started our study by obtaining two 2.5 Kg homogenous cylindrical chicken and meat mortadella tubes from Carrefour. We divided our samples into two batches: the first batch will be stored at room temperature to examine the effect of temperature and the second batch will be refrigerated to observe the effect of aging as time passes. Meanwhile, we utilized the setup shown in figure 1 to perform the measurements over a period of one week. Both aging and temperature effects were tracked using an open-ended coaxial probe and a vector network analyzer (VNA) at room temperature. Dielectric properties measurements were performed on both samples before dividing the samples into two batches (day 0) to obtain reference measurements. Subsequent measurements were performed after 5 and 7 days. For batch 2 measurement, the samples were taken out of the refrigerator and left at room temperature of 23 C to equilibrate before the dielectric properties were measured. For batch 1, the measurements were performed normally as the samples were left at room temperature. Figures 2 and 3 illustrate the obtained results of dielectric constant (ε′) and loss factor (ε″) as a function of frequency (from 1 to 6 GHz) for seven days for beef and chicken samples, respectively.

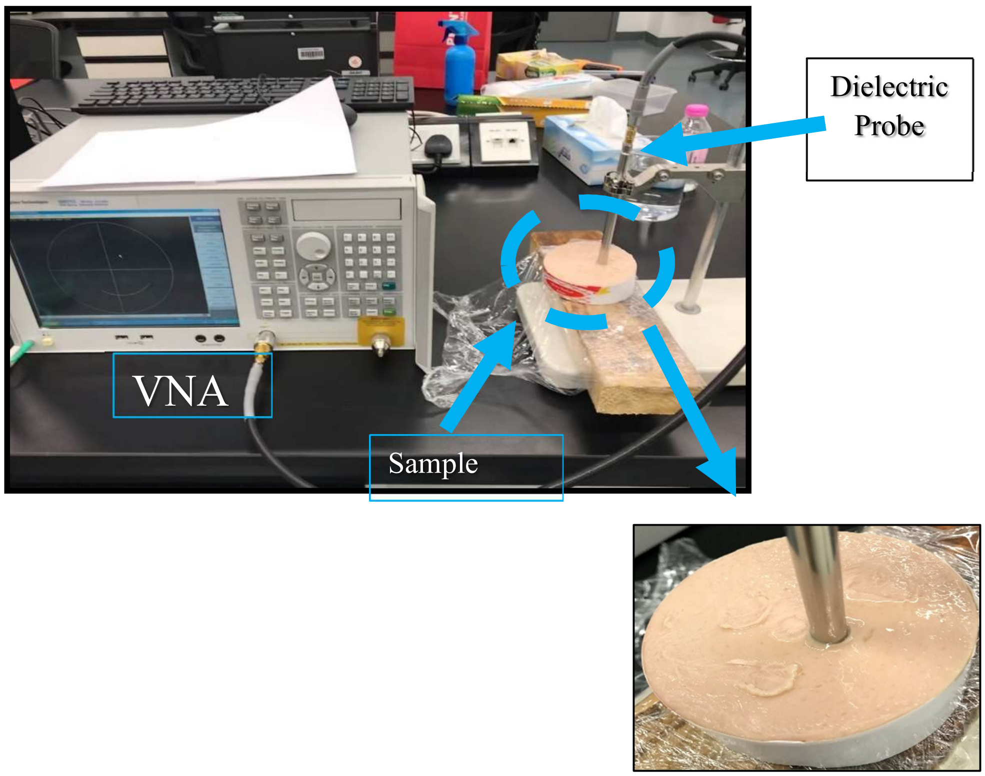

Figure 5.1.1: Dielectric Properties Measurements Setup and Chicken Sample.

For batch 1 samples, the dielectric constant and the loss factor for beef and chicken samples increased with frequency after 5 days relative to day 0. After 5 days of leaving the samples at room temperature, a slime layer was formed as seen in Figure 5.1.1 causing the dielectric properties to increase. Therefore, the effect of temperature seems to increase the dielectric constant and loss factor. However, after a week of leaving the samples at room temperature, the samples started to decompose leaving the dielectric probe to be misplaced, hence decreasing the dielectric properties of both samples. Furthermore, for batch 2 samples, the dielectric constant and the loss factor for beef and chicken samples increased with frequency after 7 days relative to day 0.

The effect of storage seems to influence the dielectric properties increasingly for both samples. These results recommend that using the dielectric property measurements to assess the quality of cold cuts is a potential method.

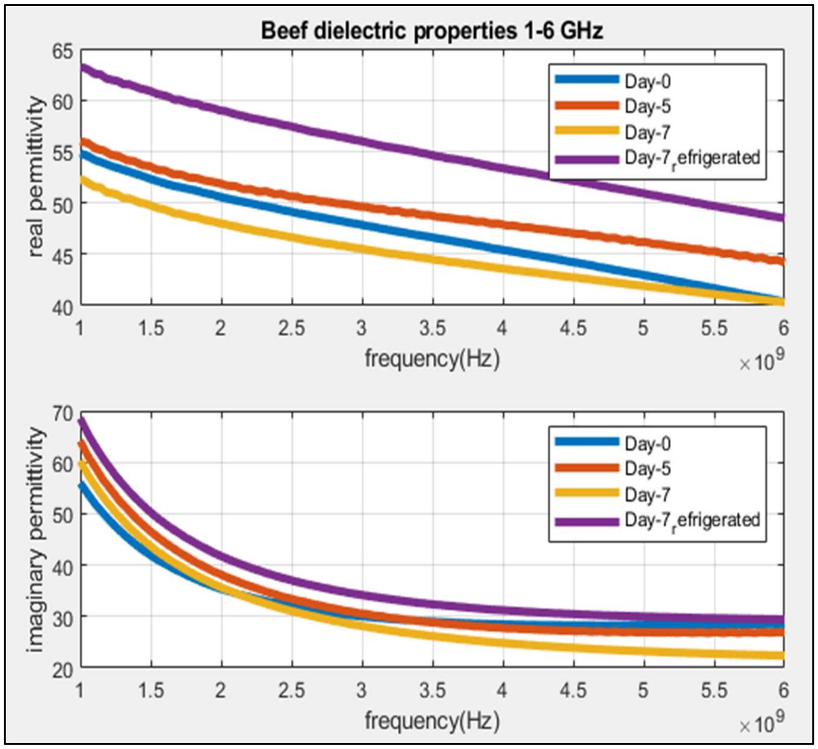

Figure 5.1.2: Results of Dielectric Constant (ε′) and Loss factor (ε″) of Beef Mortadella.

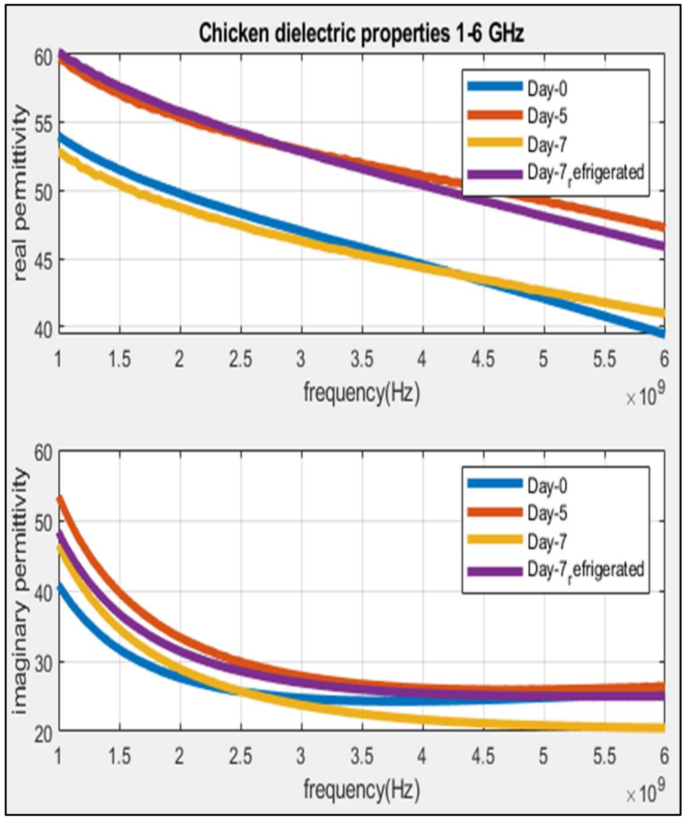

Figure 5.1.3: results of dielectric constant (ε′) and loss factor (ε′′) of chicken mortadella

We verified our study by the approach explained above to investigate the effect of different factors on the dielectric properties of cold cuts. However, multiple approaches were conducted during the semester, but they showed invalid results as they were contradicting the above approach and for other reasons. The first gradual, false study was conducted by obtaining a beef mortadella sample and leaving it at the lab temperature (almost 21 C) in contact with the dielectric probe as shown in Figure 5.1.4. This approach aimed to monitor the change in dielectric properties as time passes by recording the measurements 2-3 a day. However, as time passed, the beef sample became dry losing its moisture level and the water content the sample has. As shown in Figure 5.1.5, the beef sample became dry and lost its optimum contact with the dielectric probe hence air was introduced to the measurements. This directed to obtain wrong measurements as air has different permittivity than the sample. Furthermore, we decided to run another approach by obtaining a new beef sample but keeping the plastic layer of the sample to maintain its moisture level. We cut a circular hole in the plastic surface equal to the surface area of the dielectric probe to insert the probe inside the sample to maintain measurements as shown in figure 6. However, the beef sample had lost a lesser amount of its moister level compared to the previous case as the air gap started to develop. As the air gap started to accumulate, the measurements taken were contradicting our previous study, hence having a failed study.

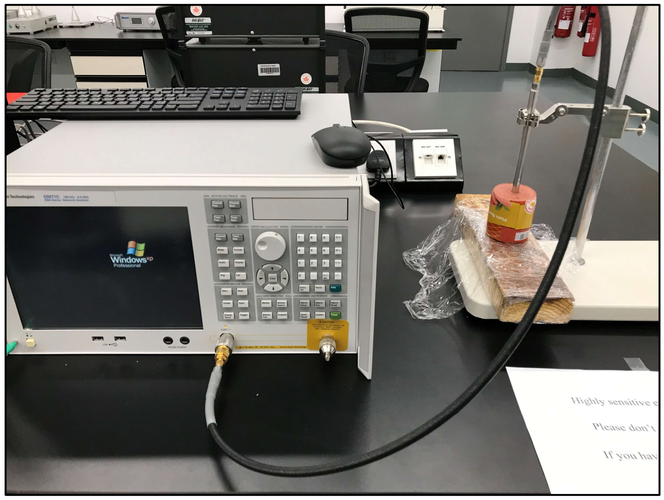

Figure 5.1.4: Beef Mortadella Sample Being in Contact with the Dielectric Probe

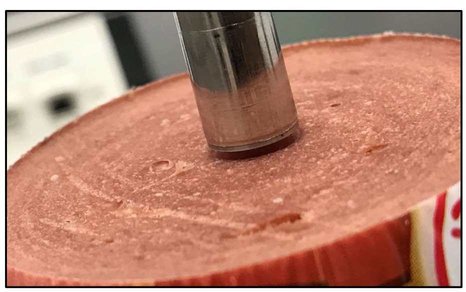

Figure 5.1.5: Dried Beef Cold Cut Sample

5.2 Proposed Solution Design Results

After establishing that the dielectric properties of cold cuts change as they spoil, the system design was next. The results indicate that the ideal frequency range for measurements is within the S-band of the electromagnetic spectrum (2-4 GHz). To choose an operating frequency for the inspection system, an experimental setup was made of a 2-3 GHz function generator, circulator, envelope detector, an antenna which was chosen to be a coax to waveguide transitional element, and a voltmeter as shown in figure 5.2.1. The setup was made such that the power reflected to the antenna can be measured. The testing methodology followed starts by measuring the power reflected when the antenna is exposed to air and then a conductor which fully covers the antenna such that the minimum and maximum amount of power received is tabulated to extract the range of measurements. Measurements were done over a frequency range of 2-3 GHz in steps of 0.1 GHz and were then normalized over their respective range such that the results at different frequencies can be compared.

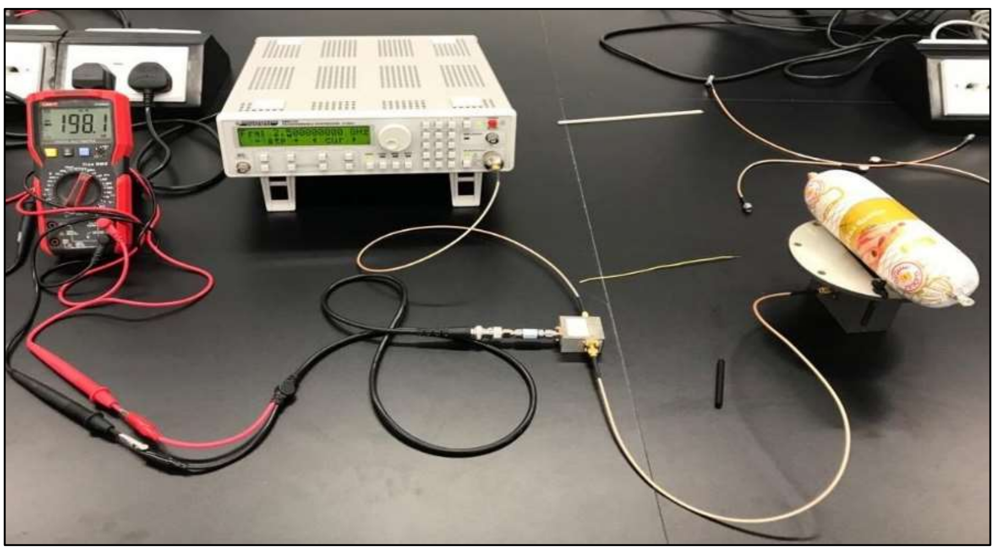

Figure 5.2: System Experimentation Setup.

The testing methodology followed involved using two samples of both beef and chicken mortadella that were left sealed and stored at room temperature. After two weeks of measurements, it was apparent that the cold cuts haven't spoiled much as the measured voltages were quite consistent. Thus, the cold cuts were cut open and examined for any noticeable signs of spoilage, and no discoloration, slime formation, or odors were noted. Consequently, it was concluded that the cold cuts did not spoil as they were not exposed to bacteria during the period of two weeks from the air or the cutting utensils used. The now cut samples were then wrapped in plastic wrapping and stored again, and a new batch consisting of two new samples which were bought and cut open, but they were stored in a refrigerator.

After 3 days, slime formation and odors were quickly apparent on the first testing batch, and the measurements showed that a relatively large change was happening in the received reflected power as shown in table 5.2.1 which summarizes the absolute percentage difference of the normalized measurements over a period of 3 days. The batch stored in the refrigerator also showed similar changes but at a much lower rate, as expected as most microbial activity is much slower at lower temperatures, as shown in table 5.2.1 which summarizes the absolute percentage difference of the normalized measurements over a period of 3 days. The results indicate that the greatest change happens around a frequency of 2.7 GHz. Thus, it was concluded that this is the optimum operating frequency for the inspection system.

Table 5.2.1: Tabulated Normalized Results for Both Samples Batches.

3 days interval Refrigerated normalized percentage difference		
Frequency(GHz)	Beef	Chicken
2	5.38%	12.10%
2.1	1.17%	6.57%
2.2	1.64%	3.64%
2.3	4.61%	3.78%
2.4	8.15%	5.78%
2.5	18.12%	4.82%
2.6	10.55%	5.02%
2.7	56.40%	17.53%
2.8	16.98%	9.26%
2.9	4.53%	2.73%
3	5.91%	0.94%

3 days interval non-refrigerated normalized percentage difference		
Frequency(GHz)	Beef	Chicken
2	10.22%	22.08%
2.1	9.34%	12.85%
2.2	10.56%	8.041%
2.3	13.65%	9.86%
2.4	29.53%	15.80%
2.5	49.08%	18.51%
2.6	34.79%	16.25%
2.7	209.10%	51.12%
2.8	50.87%	25.89%
2.9	15.82%	10.64%
3	24.42%	17.35%

Chapter 6. Conclusion and Future Work

This chapter aims to give a summary of building the system as well as go over our findings. Followed by an explanation of some of the work that we plan on doing in the future. Finally, the chapter discusses the work plan that was used to bring the project to completion.

6.1. Concluding Remarks

This project aims to tackle a real-world problem that is of highest concern. If we can successfully implement the proposed inspection system, it would become a viable solution to check whether supermarkets adhere to food safety regulations or not. Further, if the system is commercialized, the inspection system would provide consumers with a way of guaranteeing the safety of the ready-to-eat meats they are consuming as additional types and brands of cold cuts can be added to the system's database. The project results indicate that the project is feasible as it was concluded that noticeable change happens to the electrical properties of cold cuts as they spoil. Thus, commercializing and expanding the scope of this project can produce an economical and time saving product that can replace standardized microbial activity tests that are currently used within the food industry.

However, due to the limitation of the equipment used, it must be noted that the repeatability of the results shown here is debatable. Also, the procedures followed were not done in a controlled environment. Thus, the samples were exposed to different types of microbial organisms that compete to multiply and colonize the cold cut samples, and the concentration of different types of bacteria might yield different results concerning the change in dielectric properties of the cold cuts. Nevertheless, it is still expected that there will be a noticeable shift in the dielectric properties of cold cuts regardless of the dominant bacteria type present in them. The procedures followed in this project can be enhanced by performing tests in a controlled environment where samples are exposed to only one type of common food pathogens at a time such that their different effects can be studied gradually to model this change. Factors such as the storage temperature, humidity, cold cut PH level, water activity, and moisture content of the cold cuts can be considered as they dictate how microbial growth happens typically.

6.2. Future Work

- Our final design consisted of using a microcontroller that would be used to generate results after performing necessary computations. We would develop an appropriate classification algorithm which could use a frequency-modulated wave as the excitation signal of the system such that decision making is based on multiple frequencies instead of one. This would lead to more consistent results and would also reduce the processing time needed to generate the results. These results can then be displayed on an LCD which would help the end-user know the quality of the meat.
- While performing tests, we noticed that in higher frequency ranges there is a chance that we will be able to get better results as the water content of the cold cuts could be a factor leading to better results at higher frequencies since the cold cuts have a relatively high moisture content, and water does not follow a linear pattern in its dielectric properties. However, further testing is required to make sure whether our hypothesis is correct or not.
- Our current design utilizes a function generator as an RF source as we were still performing tests to figure out which frequency would yield the best results so to make our system portable and make it more consumer-friendly we would ideally use a Gunn-Oscillator or a voltage-controlled oscillator instead as that is more portable than a function generator.
- Cold cuts are sold in various configurations and may use different condiments while preparing the cold cuts making them non-homogeneous. This would change the properties of the cold cut samples and would require further testing to determine whether they are good or bad quality. We would like to build a system that will be able to determine the quality of all cold cut types.
- Finally, we would ideally use a patch antenna instead of the waveguide to coaxial transition as our antenna however, due to the time constraints and the PCB lab in the university under renovation we could not make a patch antenna as planned.

6.3. Work Plan

1. Literature review to understand the importance of the subject and understanding the changein dielectric properties in different food products.

2. Testing the food samples in the microwave lab to measure the dielectric properties to create a benchmark that can be used to compare the different food samples tested under different conditions.
3. Measuring the change in dielectric properties and finding a correlation between the dielectric properties and other parameters such as texture, color and so on.
4. Analyzing the data obtained to understand which components are needed to make similarconclusions.
5. Building a functional prototype that will be able to determine whether the food sample issafe to consume or not.
6. Tweaking certain parameters in the code to make sure that all the parameters are beingtested and make sure that the prototype is working properly after making said changes.

	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8
1								
2								
3								
4								
5								
6								

Table 6.3: Estimate Timeline of Completing the Project Before the Graduation

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