REPUBLIC OF TÜRKIYE
ALTINBAŞ UNIVERSITY
Institute of Graduate Studies
Electrical and Computer Engineering

DESIGN A BOW-TIE ANTENNA AND BREAST PROTOTYPE FOR HYPERTHERMIA APPLICATION

Abdullah Isam Mosa AL-ARAJI

Master's Thesis

Supervisor
Prof. Dr. Galip CANSEVER

Istanbul, 2022

DESIGN A BOW-TIE ANTENNA AND BREAST PROTOTYPE FOR HYPERTHERMIA APPLICATION

Abdullah Isam Mosa AL-ARAJI

Electrical and Computer Engineering

Master's Thesis

ALTINBAŞ UNIVERSITY

2022

The thesis titled DESIGN A BOW-TIE ANTENNA AND BREAST PROTOTYPE FOR HYPERTHERMIA APPLICATION prepared by ABDULLAH ISAM MOSA AL-ARAJI and submitted on 13/12/2022 has been **accepted unanimously** for the degree of Master of Science in Electrical and Computer Engineering

____

Prof. Dr. GALİP CANSEVER

Thesis Defence Committee Members:

Prof. Dr. GALİP CANSEVER	Department of Electrical-Electronics Engineering, Altınbaş University	________________
Asst. Prof. Dr. SEFER KURNAZ	Department of Computer Engineering, Altınbaş University	________________
Asst.prof. Dr. Yüksel BAL	Department of Computer Engineering, Topkapı Üniversitesi	________________

I hereby declare that this thesis meets all format and submission requirements of a Master's thesis.

Submission date of the thesis to Institute of Graduate Studies: __/__/__

I hereby declare that all information/data presented in this graduation project has been obtained in full accordance with academic rules and ethical conduct. I also declare all unoriginal materials and conclusions have been cited in the text and all references mentioned in the Reference List have been cited in the text, and vice versa as required by the abovementioned rules and conduct.

Abdullah AL-ARAJI

Signature

DEDICATION

First and last, I am thankful to Allah for the excellent health to complete this thesis.

Grateful to my family and especially to my mom for her endless love and permanent support.

Grateful to my primary supervisor Prof. Galip CANSEVER for his guidance, advice and everything.

I appreciate the great woman Suhair FAWZI for teaching me and for her support.

ABSTRACT

DESIGN A BOW-TIE ANTENNA AND BREAST PROTOTYPE FOR HYPERTHERMIA APPLICATION

ALARAJI, Abdullah

M.Sc. Electrical and Computer engineering, Altınbaş University,

Supervisor: Prof. Dr. Galip CANSEVER

Date: 13 /12 /2022

Pages: 63

In this work we construct an antenna that is suitable for use in applications involving hyperthermia. The antenna we are going to build should be able to radiate in a material that absorbs energy (breast), have a working frequency of 900MHz. This very high temperature is effective in eliminating the cells that are malignant. There are several ways to optimize the performance of a hyperthermia. The main goal is to target heat energy into the tumor area, creating a highly localized heating region. The more energy/power deposited into the tumor, the higher the temperature elevation. At the same time, the temperature of healthy tissues should be kept below critical levels. The main design parameters of a hyperthermia applicator need to be determined and optimized in order to meet all these requirements. An advantage of this antenna is a small size, which measures just (30 × 30 mm) makes it simpler to construct and include into an applicator that has the capacity to hold many antennas.

Keywords: (UWB, Bow-tie Antenna, CST Application, SAR).

TABLE OF CONTENTS

Pages

LIST OF TABLES

<u>Pages</u>

LIST OF FIGURES

Pages

ABBREVIATIONS

CST : Computer Simulation Technology

SAR : Specific Absorption Rate

ISM The Industrial, Scientific, and Medical

S11 : S-Parameters

dB : Decibel

Hz : Hertz

UWB : Ultra-wideband

HF : High frequency

UHF : Ultra-high frequency

PVC : Polyvinyl chloride

cm : Centimetre

Mm : Millimetre

RF : Radiofrequency

1. INTRODUCTION

1.1 HYPERTHERMIA TO TREAT CANCER

The term "hyperthermia" typically refers to either an increase in the temperature of the human body to an abnormal range or the process of treating the body for a particular disease by applying a heating source, which leads to heating the whole body or some part of the human body for a particular period of time. Both of these scenarios can lead to an increase in the temperature of the human body. Through the use of electromagnetic radiation, the microwave hyperthermia therapy often raises the temperature of a particular portion of the human body to a range that falls between (41-43°C) [1]. Today, hyperthermia has been put to use in the treatment of malignant tumors located inside the human body. This is accomplished by applying heat to the affected tissues using a variety of tools.

Because of the growing interest that has been shown in the hyperthermia therapy over the last several years. It has been used as an adjunct treatment in conjunction with radiation and chemotherapy. The malignant cells may be killed or damaged, if they are subjected to a high temperature for an extended period of time. Heating causes tumor cells to shrink because the heated tumor cells are more responsive to chemotherapy and radiation therapy than normal tissues [2]. Normal tissues are less sensitive to these treatments than the heated tumor cells. Because of increased vascularization, blood flow to malignant tumors is often lower than that of normal tissues [3]. This causes electromagnetic radiation to have a suppressing effect on the resistance of tumor cells. The blood flow is used during the hyperthermia treatment in order to boost the perfusion, which in turn increases the effectiveness of medication delivery as well as radiation or chemotherapy [4, 5].

The use of hyperthermia has a number of benefits, but there are also a number of hurdles that arise as barriers to the use of hyperthermia. One of these concerns is that heating the region containing tumor cells might cause harm to the surrounding healthy tissues.

In most cases, hyperthermia is caused by applying the least amount of heat, which is between (41 and 43°C). The temperature range that is optimal for thermal ablation is typically between (45 and 90°C) [6].

Body temperature can be raised from dielectric losses by electromagnetic waves and from mechanical losses by applied ultrasound. There are a few of different approaches that have been suggested for making use of hyperthermia treatment. The two methods are separated into two categories according to the method that will be used to deliver the heat to the tumor. The first technique is known as hyperthermia in the local area. During this procedure, ultrasound, microwave, or radiofrequency energy is used to provide heat to a localized region or the tumor itself in order to destroy it. Regional hyperthermia is the other kind of hyperthermia treatment that may be used. During this procedure, the heat will be administered to a wide region of tissue, such as an organ, a limb, or a cavity inside the body. In this scenario, the whole area will be thought of as extended tissue and will be heated using radiofrequency or microwave radiation. There are also three major methods of generation of local hyperthermia: external, luminal and interstitial. External heating methods are simple to be handled. However, they pose challenges to get the energy deposited into deep and narrow tumor locations [7].

Hyperthermia treatments have proved to treat several malignant tumor types, including those of the head and neck, brain, kidney, and breast. The likelihood of curing cancer depends on where it is in its development [8].

The use of hyperthermia as a cancer therapy has increased during the last several decades. In addition, a lot of women get breast cancer throughout the course of their lives. According to the study, 12% of women will develop breast cancer at some point in her life time [9]. In general hyperthermia is used in conjunction with Conventional treatments of cancers include chemotherapy, radiotherapy, and surgery. Although microwave hyperthermia, which is increasing the temperature of cancerous tissue to 45°C, has been studied over the past four decades, recent clinical trials have shown promising results when used in conjunction with radiation and chemotherapy. This type of therapy exposes cancer cells to electromagnetic energy as heat, thus reducing the resistance of the cancer cells for the affected tissue. Because vascularization and blood flow in tumors is lower than that of regular tissue, cancerous cells are more heat sensitive than normal tissue. The treatment of breast cancer using hyperthermia will be the main emphasis of this paper.

The treatment of cancer, particularly the removal of breast cancer tumors, may benefit greatly from hyperthermia. It's possible to get a therapeutic result with a different kind of hyperthermia therapy without requiring surgery. The heat must be adjusted to just warm the malignant tissues in order for the hyperthermia therapy to be successful. To avoid injuring any healthy tissues, it is essential to deliver the heat to the malignant tissues without subjecting the good tissues to an elevated temperature. A straightforward approach for creating an annular phased array with dipoles of linear half wavelength is provided in [10]. It has been computed how the temperature varies inside breast tissues like a tumor, breast, and skin model. To produce hyperthermia for the treatment of breast malignant tissue, the effect of altering the phase and amplitude of the array element on the heat dispersion is shown.

On patient breast models, another electromagnetic implementation approach is shown. This method seeks to concentrate energy in the chosen location while maintaining the surrounding healthy tissues at body temperature. This can be noticed by optimizing the phase of the excitation of the used elements [11].

By employing the thermal analysis to establish the scaling factor for the antenna, the required temperature for the tumor region may be realized. The method has been closed-looped to ensure that no heat is sent to the healthy tissues. A 3-D realistic environment of the breast and antenna system was used to test the approach. In order to improve the heat delivery further, we introduce the optimal frequency as a treatment planning parameter, which can be specified for each patient and each tumour position. On one hand, we can foresee that using of higher frequencies is beneficial for treatment of small tumours as it reduces the focal spot size. On the other hand, low frequencies are preferable in the case of large or deep-seated tumours. The findings indicate that for dense and fatty breasts, 4.2 GHz and 4.5 GHz frequencies are ideal for hyperthermia cancer therapy.

1.2 ANTENNAS FOR HYPERTHERMIA

There are several distinct antennas used for hyperthermia applications, and each antenna differs from the others in terms of characteristics and forms. In this part, we'll concentrate on the antennas that have been proposed for applications using hyperthermia and the crucial factors that must be taken into account.

One challenge of hyperthermia treatment is the difficulty of delivering energy to deep tumors. This challenge can be addressed using relatively low values of excitation frequency. Another challenge is the ability to confine energy with high precision to the tumor locations, which can be achieved depending on higher frequency ranges. UWB operation thus provides an attractive capability for hyperthermia systems.

Ultra-wideband (UWB) antennas operating at frequencies below 1 GHz are rather uncommon in biomedical applications of EM fields. Hyperthermia applicators tend to operate at ISM frequencies allocated for industry, science and medicine and therefore tend to use narrow-band antennas such as waveguides, dipoles or patch antennas.

For applications involving hyperthermia, the performances of the most popular antennas have been studied. Bow-tie-shaped antennas are one kind of such antenna. Bow-tie antenna is a half-wavelength dipole antenna. The operating frequency of this antenna relies on its length and, at the target frequency, should be equal to the wavelength divided by two. The angles are another factor that may be taken into account.

A frequency-independent antenna is one whose performance is significantly influenced by the Bow-tie antenna's design and angles [12]. The Bow-tie antenna has been a useful antenna for applications involving hyperthermia for a few decades. The Bow-tie antenna was presented by several researchers in a variety of sizes and forms [13]. The Bow-tie antenna was described as a self-grounded antenna in [14, 15]. The idea behind this design is to twist the antenna's arms in the direction of the Bow-tie antenna's feed point in order to increase their length. The Bow-tie antenna's working frequency is dependent on the length of the arms; hence it works in a low-frequency band as a consequence. The antennas used in the aforementioned studies operate at 400 and 700 MHz. The purpose of operating the antenna at a low frequency is to improve the depth of penetration and beam intensity. In certain documented studies, antennas are submerged in deionized water, which is typically employed as a cooling liquid and also to reduce the size and provide a good impedance match to the patient.

The spiral antenna is another common kind of antenna that is used for hyperthermia. The spiral antenna is a member of the frequency-independent antenna group, which is a collection of antennas that are known for having a very wide bandwidth. The performance of a spiral antenna is determined by several characteristics, such as the overall length of the spiral, the spiral's outer radius, and the flare rate. The lowest possible frequency of operation is determined by the outside radius of the spiral. The angle that determines the size of the following spiral may be thought of as being representative of the flare rate [16].

The antenna will be tightly wound around itself if the flare rate is high, producing a capacitor effect. On the other hand, the antenna will behave like a dipole antenna, if it is small. In the literature, several spiral antennas have been suggested for hyperthermia, although the proposed antennas often do not incorporate major form changes. The majority of the designs contain one or two arms [16].

It is detailed in reference number [17] how a four-arm spiral antenna may be used for microwave hyperthermia. With the use of the finite element approach, we were able to model both the electromagnetic and the SAR distributions. It has been shown in phantom muscle tissue how the distribution looks. According to the findings that have been presented, the heating area of the four-arm spiral antenna has the potential to alter depending on the frequency of the input excitation.

SAR is a quantity that describes the amount of absorbed radiated effect for a specific material at a certain frequency. The specific absorption rate (SAR) is an index that quantifies the rate of energy absorption in biological tissue.

In [6], there is a representation of a two-armed Archimedes planar spiral microwave hyperthermia antenna. The antenna that has been provided is insensitive to both the variations in the input frequency and the spiral antenna characteristics. Changing the input frequency from 915 to 2450 MHz is a straightforward way to exert control over the size of the heating region, which is essential for avoiding damaging the normal tissue.

Using the finite element approach, we were able to replicate the distribution of both the electromagnetic and the SAR fields produced by the heated tissue. Comparisons are made between a wide variety of parameters, including those that have the potential to influence the performance of the antenna, such as the diameter, spiral circle, and circle numbers of the nearby spiral wire. The applicator, which was described in[18], exhibited an acceptable level of reduced return loss throughout a broad bandwidth range. It is capable of generating a variety of heating patterns and demonstrates the capacity to change SAR to conform to a certain shape. In order to improve SAR distribution in the treated area, the recent trend in hyperthermia is to utilise applicators holding a number of antennas that operates at higher frequencies.

Using a single antenna for heating a tumor increases the value of specific absorption rate (SAR) close to the surface. A phased antenna array is an attractive solution for deep tumors. The aim is to transmit electromagnetic signals that constructively interfere at a tumor location and destructively interfere outside this region, providing selective absorption of electromagnetic energy.

In this case [19], the antenna was working at a rather low frequency. Altering the antenna's arm configuration and submerging it in a water bolus are the two steps necessary to accomplish the final goal. According to [20], the antenna is capable to operates at many frequencies, which is 450, 550, and 700 MHz. Because it contains these frequencies, it is well-suited for use in hyperthermia applications.

A planar antenna that generally works in a broadband mode is called a Vivaldi antenna. It has a straightforward design, and the working frequency is often determined by the dimensions of the antenna in addition to the magnitude of the slot and the manner in which the Vivaldi antenna is formed. Typically, for hyperthermia applications, the Vivaldi offers a great tool to construct UWB antennas with additional benefits like as broad bandwidth, compact size, symmetrical beamwidth, and good directivity. This is because the Vivaldi was developed specifically for this purpose. Adjusting the size of the antenna as well as the other characteristics, such as altering the primary form of the antenna by include corrugation in the construction of the antenna. This modification makes it possible for the antenna to operate at lower frequencies while maintaining a wider bandwidth.

A novel ultra-wideband Vivaldi antenna for hyperthermia treatment of human head is presented in the work that may be found in reference [21]. The antenna is constructed to have a diminutive size (82x92x1.6mm). The distinctive structure of the Vivaldi antenna exhibited the antenna's performance, which was superior to that of the other design in terms of aspects like the return loss. The distribution of the absorption rate is improved inside the head. The simulation was carried out utilizing the following four backdrop materials: brain, air, oil, and water. In [22], an antenna called the Vivaldi was designed specifically for use in hyperthermia situations. When compared to the other work that was given, the total size of the antenna is rather tiny. The antenna is submerged in a liquid that mimics the activity of the brain. This showed very successful results for the array in directing energy in the desired location of the tumor.

Another study [23] has shown a Vivaldi antenna design that may be used to cure malignancies in the human skull using hyperthermia. When testing the antenna, we employed a variety of different backdrop materials like oil, air, water, and brain-simulated fluids. In order to boost the antenna's ability to penetrate the brain, it was built to operate in the UWB range while also working in the low-frequency region. By using high frequencies, it is possible to concentrate the microwave radiation where it is needed most, which is in the malignant tissues. For the purpose of researching a hyperthermia therapy, a phantom model was used. According to the findings, the optimization procedure has an effect on the manner in which the SAR is distributed inside the phantom model.

The Yagi-uda antenna will be the subject of the last discussion on antennas. The Yagi antenna is known for its high gain and its very simple construction. In addition to this, it has a narrow bandwidth and operates in both HF and UHF. The dimensions of the antenna are the parameter that may offer a crucial modification in a Yagi-uda antenna. A Yagi-uda antenna will often have two passive components, known as a director (located on the front side) and a reflector (backside). A printed circuit wide antenna was introduced in [24] for both the design and the high-frequency validation of the antenna (433 MHz). The work that has been provided may be used wonderfully in a variety of different hyperthermia system designs. The findings of the clinic demonstrate that the antenna has perfect matching qualities across a bandwidth reflection coefficient that is less than -15 dB and has 7.2 % bandwidth.

1.3 PHANTOM MATERIALS USED FOR HYPERTHERMIA

Because of the recent rise in the number of women who are being told they have breast cancer; researchers have been focusing a lot of their attention on this disease in recent years. It does not make sense to use human breast to test all of the applications that were presented to treat breast cancer for many reasons, including the limited sources for some researchers, the fact that some applications cause temporary or permanent damages, and the fact that using real human breast would be more expensive than using phantoms that can be used as a realistic breast tissue. However, there were many applications that were presented to treat breast cancer, and these applications need to test their antennas. Due to the difficulty of obtaining real tissue, a researcher proposed. As a result, a phantom is used for the purpose of simulating the dielectric characteristics of breast tissue.

It is necessary to take into account a variety of parameters in order to meet the majority of application requirements. Some of these parameters include the size of the breast, the volume of the breast, the thermal and dielectric properties of the breast, and the tissues that work together to imitate a real breast. In this chapter, we will review a summary of the most popular phantom recipes and elements that are used to create a phantom material that may be employed for hyperthermia applications. Many phantoms have been shown that can be used as a realistic breast.

Gelatine, deionized water, oil, sodium chloride (salt), a surfactant, and propylene glycol are the components that were employed the most often in the process of synthesizing phantom materials. Phantom materials that may imitate diverse human tissues, such as glands, fat, skin, and cancers, can be created by combining a particular quantity of each of these materials together in the appropriate proportions. A breast phantom that is provided in this article [25] is capable of meeting the thermo-dielectric characteristics of the human breast. The authors were able to produce three distinct tissues by combining gelatine, deionized water, and oil in varying proportions and mixing them together (Gland, Skin, and fat). Tumor tissue may be recovered from the solution by first adding salt to it [26, 27].

Other studies have presented phantoms that comprise the previously specified constituents (Gelatine, oil, water, salt, surfactant, and Propylene glycol), but the proportions of these components were mixed differently. The goal of this is to get extra tissue with dielectric characteristics. This is possible since the tissues may be categorized as having either a high, medium, or low water content [28, 29].

The preparation of more phantoms for use in hyperthermia applications was underway. When it comes to the construction of this phantom, a wide variety of materials are utilized [30]. The following component may be found in the amalgamation of this phantom: (oil, propylene glycol, Byk-011, Despoil, HCl, formalin, and alizarin dye). The recipe for constructing this phantom is, in some ways, similar to the one that was discussed before.

Various kinds of materials and methods have been discussed. According to [31]33], a substance that resembles tissue may be manufactured by combining PVC powder with softener (i.e., dioctyl terephthalate). When the desired temperature for the PVC mixture was obtained, graphite powder was added to the mixture. Then the result use in the creation of a breast phantom that replicates the characteristics of a real breast.

The phantoms that need to be utilized and evaluated at high frequencies were the focus of the proposal that resulted in the creation of a phantom that is used for high-frequency applications [25]. The planned phantom was constructed from of materials that were both more stable and more costly. The main component of this phantom is Agar, which was used for the aim of providing solidification. The phantom mixture was made up of six ingredients, which are as follows: deionized water, glycerol, benzalkonium chloride, agar, and silicon carbide. Each of these ingredients was added at a different stage of the recipe for preparing the phantom, and each one is typically added by a specific ratio to produce the desired effect [25]. The phantom was created by combining the ingredients.

1.4 SUMMARY OF WHAT WILL BE CONVEYED IN THE REST OF THE THESIS

According to the previous discussion, a large number of antennas are provided to be used for applications involving hyperthermia. The purpose of this thesis is to create an antenna that has the potential to be used in the treatment of breast cancer through hyperthermia. The primary goal of the hyperthermia treatment is to get the temperature of the tumor up to between 41 and 43°C. It is necessary for us to determine which antenna will be used in order to meet the needs of the application before we can make these phenomena relevant. By doing research on the majority of the antennas that have been put up as potential candidates for a functional and effective antenna for hyperthermia.

In the end, we decided to go with a bow-tie antenna. Some of the benefits that can be achieved with a bow-tie antenna are bandwidth, size, ease of manufacture and operating frequency. After determining which antenna would work best for our application, we will begin constructing a Bow-tie that will be appropriate for hyperthermia devices. The most important feature that we have to take into account is the size of the antenna, which has to be compact enough to be used in an array of antennas that are wrapped around the breast. In our situation, a distance of 3cm would be plenty to make the antenna usable in hyperthermia arrays.

The frequency at which the system is run is yet another important criterion that must be addressed. Our objective is to improve the antenna's penetration depth and heat distribution throughout the tumor by tuning it to 900 MHz so that it can radiate at that frequency. The bandwidth is the last metric that must be enhanced to meet the requirements. An additional objective is to provide the antenna the capability of operating at a broad bandwidth of around 2 GHz. The software that is included in the CST studio suite is used in order to simulate and test the planned antenna. The antenna is examined while it is attached to a phantom that represents the human breast. In our simulation design, the antenna has been examined while it is attached to a phantom that represents the human breast.

For the phantom, we will try to analyse the dielectric properties (permittivity and conductivity) and the boiling points of a wide variety of materials in order to find materials that match the dielectric properties of water and oil. Additionally, we will use materials that are able to handle a higher temperature, which will allow the phantom to be suitable for hyperthermia applications that involve a high heating rate. In addition to this, we will make an effort to use certain formulae in the hopes of estimating the permittivity of the combination without having to do any actual tests.

1.5 THE GOALE

The aim of this thesis is to develop hyperthermia applicators for treatment of breast tumours. There are several ways to optimize the performance of a hyperthermia. The main goal is to target heat energy into the tumor area, creating a highly localized heating region. The more energy/power deposited into the tumor, the higher the temperature elevation. At the same time, the temperature of healthy tissues should be kept below critical levels. The main design parameters of a hyperthermia applicator need to be determined and optimized in order to meet all these requirements.

This range of frequency will lead us to enhance the concentrating on the target tumor and elevate its temperature to over 42°C, therefore the objective is to construct a Bow-tie antenna that can radiate in broad bandwidth and to operate in 900 MHz. This very high temperature is effective in eliminating the cells that are malignant. Keeping the temperature of the healthy tissues within the normal range enables the balun to simultaneously lower the temperature of the region around the tumor. Another advantage of this antenna is a small size, which measures just (30 × 30 mm) and makes it simpler to construct and include into an applicator that has the capacity to hold many antennas.

On the other hand, the antenna was evaluated using a simulation that included two components. First, the cooling system, which is the first layer in this system after the antenna, is used to cut down on the amount of heat that is applied to the skin tissue second, the phantom layers, which include the skin and fat. In order to construct the phantom, we are going to investigate the dielectric characteristics (permittivity and conductivity) of a wide variety of materials in order to locate substances that have dielectric properties that are comparable to those of water and oil. In addition to this, we are going to make an effort to use a few equations that have the potential to assist us in determining the permittivity of the mixture. In terms of electromagnetic modelling, it is also utilized to simplify the process of representing the heterogeneous breast tissue as a single homogeneous material. This allows the dielectric characteristics of the heterogeneous breast tissue to be modelled in a manner that is relatively straightforward.

1.6 THESIS OUTLINE

This chapter explains why this study was done and provides a summary of the research that has been done so far on using hyperthermia as a therapy for breast cancer. In the second Chapter, an analysis, testing, and comparison of the materials that are utilized to construct a new phantom with improved qualities, such as being able to withstand greater temperatures and having a longer shelf-life, are presented. The third chapter provides an introduction to the Bow-tie antenna as well as an in-depth analysis of the process of creating a new Bow-tie antenna that is adaptable to a wide variety of thermal applications. Lastly, the working paper concludes with a summary in the fourth Chapter along with some suggestions.

2. PHANTOM FABRICATION

2.1 INTRODUCTION

In the last ten years, researchers have shown increased interest in microwave hyperthermia and imaging applications as a result of the need for innovative technologies for the treatment of breast cancer and the detection of the disease. The goal of increasing the temperature of the tumor to more than 43˚C in order to treat breast cancer using a microwave is to kill the tumor tissue while maintaining the normal temperature of the surrounding healthy breast tissue [32].

At the moment, the therapy for microwave breast hyperthermia is conceptualized inside a computer setting. Because non-invasive changes to the temperature of tissue are limited, testing can only be done on phantom materials [36]. Phantom materials are often used for testing purposes during the pre-clinical stages of developing microwave-based medical devices. Phantom tests enable the use of conventional thermometers based on fibrotic technology for testing hyperthermia systems. Therefore, phantom tests are crucial benchmarks that are necessary in order to enable the pre-clinical evaluation of the simulated system characteristics. Therefore, a realistic breast phantom that is capable of replicating the electromagnetic and thermal characteristics of the human breast is able to properly portray temperature distribution throughout the breast volume [32].

There are a lot of distinct breast phantoms that have been published in the literature for use with microwave breast cancer imaging and hyperthermia. The oil-in-gelatine dispersion phantoms are a common kind of phantom material that is used for breast cancer imaging and hyperthermia. These phantoms are created by combining deionized water, gelatine, oil, and surfactant as the primary components in order to make a chemical gel. There has been a lot of research done in the academic literature on the dielectric characteristics as well as the thermal properties of oil-in-gelatine dispersion phantoms [25, 32].

Phantoms that look like breasts and brains were described in reference [33]. The phantoms were created by combining varying amounts of TX-100, deionized water, and NaCl in a mixing vessel. In a different piece of research [34], a combination of polyvinyl alcohol cryogel (PVA-C) and sucrose was utilized to simulate the dielectric characteristics of human tissues. Another research employed agarose, maize oil, distilled water, and neutral detergent to create a breast phantom that replicated the dielectric characteristics of healthy breast tissue. This phantom was used to test the effects of breast implants. In the same work, a model of cancerous tumor tissue was created using ethanol, NaCI, agarose, and distilled water [35]. In a separate line of studies, a thermal phantom was created for use in hyperthermia applications. In this phantom, acrylamide monomer, ammonium persulfate, methylene-bis-acrylamide, thermochromic dye, and tetramethylethylenediamine were the components that were used.

In order to conduct research on hyperthermia, this phantom has been programmed to emulate the behaviour of bodily tissues. The proposed study shows that the mentioned recipe is only useable for a range of temperatures between (45-55˚C). There is a possibility that it is not applicable for the application of moderate hyperthermia, which is employed with a lower degree of temperature (40-45˚C) [36]. On the other hand, a thermochromic dye with a lower threshold should be utilized in order to provide the phantom the ability to withstand this temperature [37].

In the most recent work, an agar phantom that has seen widespread use in RF heating is shown. The phantom is made up of water (95.5-95.3 %), agar powder (representing 4% of the total), NaN3 (representing 0.1%), and NaCI (representing 0.6%). The agar phantom demonstrates sufficient strength to enable the building of a torso that is 60cm in height. In addition, this phantom might be put to use for conducting thermal tests like heating since it has the potential to last for a whole year without deteriorating [38].

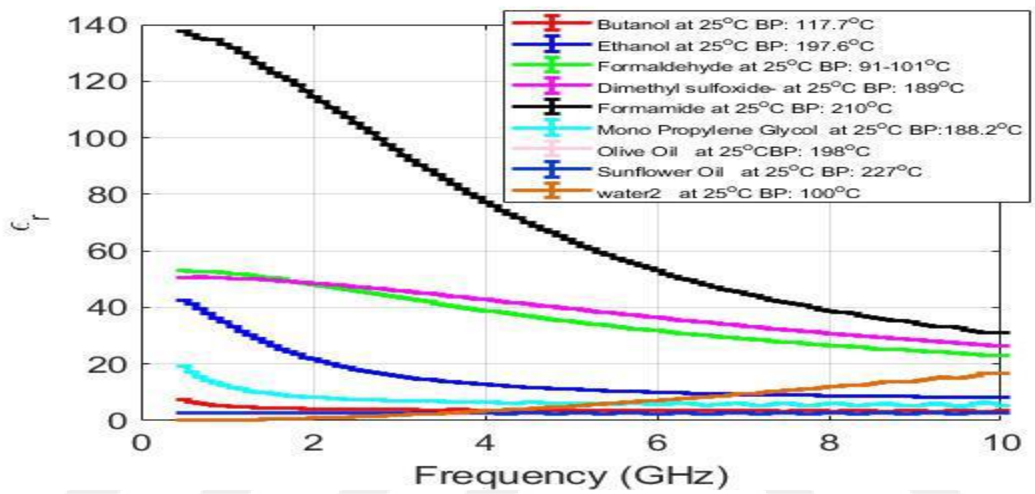
There are several limits placed on the phantom characterization process for microwave system testing. These limitations include the dielectric property requirements, shelf-life restrictions, and ingredient availability. For the most part, phantoms that are defined for use in testing hyperthermia devices should ideally approximate the thermal characteristics of breast tissue and be reusable through numerous heating and cooling cycles. With a few notable exceptions, the previously published phantom research concentrated only on recreating the biological materials' dielectric and thermal characteristics while ignoring any other relevant factors.

Phantom materials based on dimethyl sulfoxide (DMSO) that imitate the dielectric characteristics of breast tissue are reported in this work. During the process of creating the suggested phantoms, both a lengthy shelf life and reusability were taken into consideration. As a result, a chemical-based phantom substance with a high boiling point was used rather than a phantom composed of deionized water. This work studies empirical ways for calculating permittivity with the goal of adopting an analytical approach rather than the conventional method of learning by trial and error.

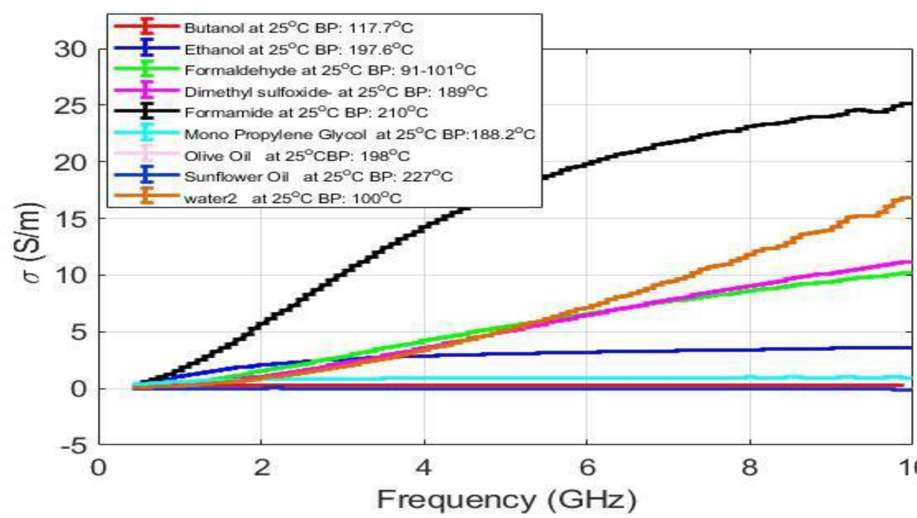
2.2 CHEMICAL SAMPLES

The purpose of this chapter is to locate materials or solutions that have Cole-Cole characteristics that are comparable to the permittivity and conductivity of water and oil. Therefore, before to beginning any kind of testing, it was necessary to take into account a few characteristics in this task. First, the permittivity and conductivity of the material have to be greater than those of the usual materials. Second, the material's boiling point has to be higher than those of the regular materials. Lastly, the compatibility of the substance with the other components that will be utilized to make a combination that will be used to simulate the tissues of the human body (phantom).

For the purpose of the testing, a network analyser was employed to offer the real and imaginary data pertaining to the materials. Conductivity and permittivity of the materials were determined by applying the conductivity and permittivity equations to the data. The first step of the experiment is to conduct preliminary tests on over twenty different materials and solutions. Following the investigation of all of those materials and the examination of their permittivity and conductivity, it was determined that seven of those materials offered the findings that were most similar to water and oil while having greater boiling points. As can be seen in Figure 2.1, the purpose of these tests is to evaluate and compare the dielectric characteristics of each material with those of water and oil. As a result of this comparison, a fair assessment can be made about the materials that would take the place of water and oil in the creation of the phantom. According to the findings, the boiling point of dimethyl sulfoxide (CH3)2SO is 189˚C, while the boiling point of 1-butanol (C4H10O) is 117.7˚C. Both of these substances have dielectric characteristics that are comparable to those of water and oil, respectively. The temperatures at which each of the chemicals that were utilized in the comparison of dielectric properties are shown in Table 2.1.



(A)



(B)

Figure 2.1: (A) relative permittivity comparison between several materials. (B) Conductivity comparisons for several materials.

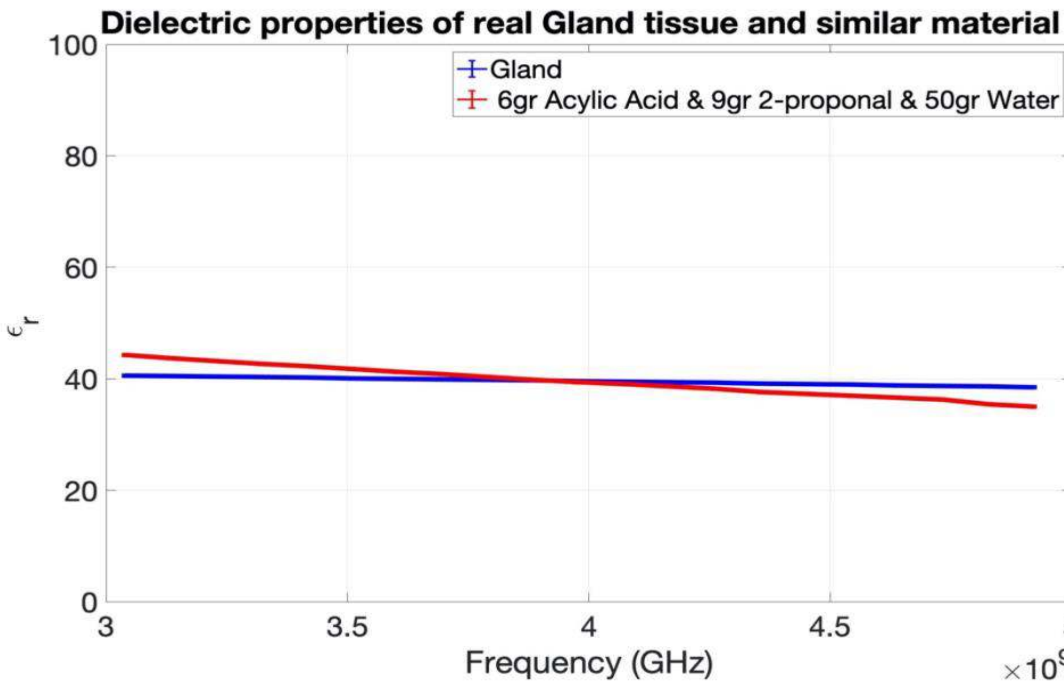
Table 2.1: Shows the chemical name and the boiling point of each material.

Chemical name	Boiling point	Chemical name	Boiling point
1-butanol	117.7 °C	Mono Propylene Glycol	188.2 °C
Ethanol	78.37 °C	Olive Oil	298 °C
Ethylene glycol	197.6 °C	Sunflower Oil	227 °C
2-propanol	82.5 °C	Distilled water	100 °C
Formaldehyde solution	91° - 101°C	Dimethyl sulfoxide	189 °C
Formamide	210 °C		

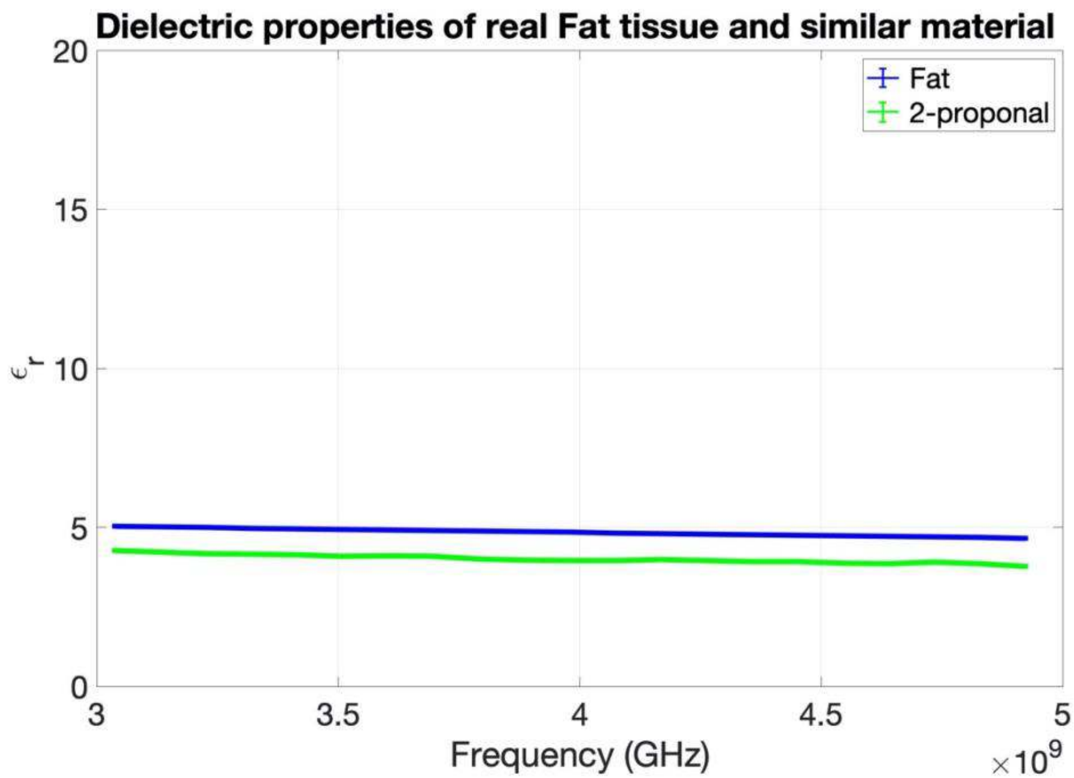
2.2.1 The Breast Tissue's Dielectric Characteristics

In this part of the process, the objective is to acquire phantom materials or combinations that have the ability to imitate the dielectric characteristics of breast tissue. By doing a wide variety of comparisons between the information in the published literature and the actual dielectric characteristics of breast tumors, glands, skin, and fat. It is possible for us to create mixes with permittivities that are comparable to those of breast tissue permittivities. The fundamental concept is to select a material that has dielectric properties that are analogous to those of one of the breast tissues. Then, by combining this material with either another material or the same material but in a different proportion, we can create a mixture that has a permittivity that is analogous to that of the breast tissue.

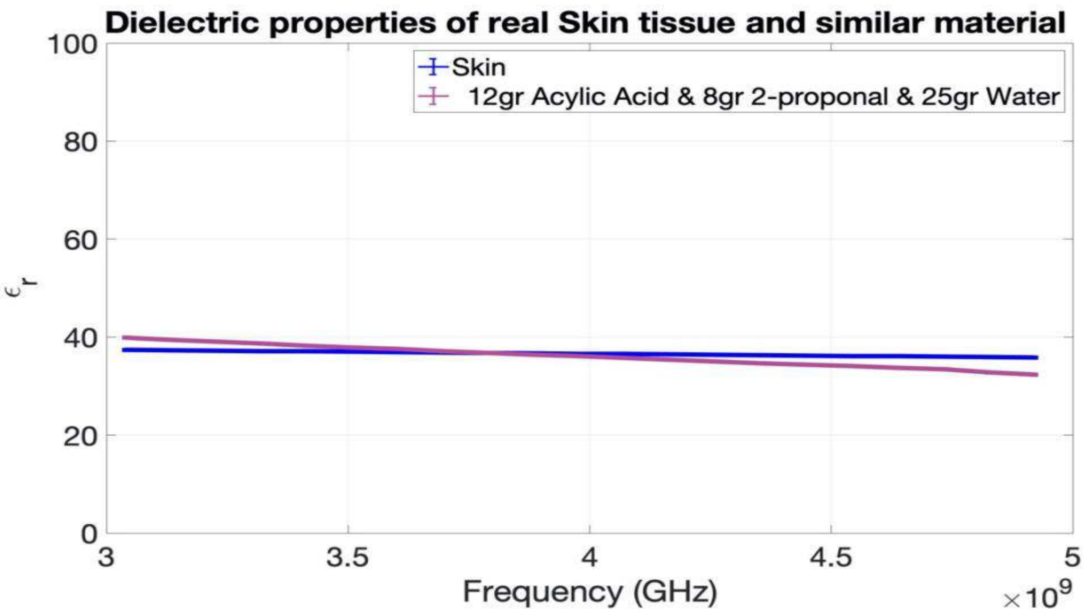
After conducting a large number of experiments, we were able to identify four primary materials that, within a certain frequency range, had dielectric characteristics that were comparable to those of breast tissue. The materials and mixes that were utilized in the testing to duplicate the permittivity of the four types of tissues are shown in Figure 2.2.


Dielectric properties of real Gland tissue and similar material
Gland
6gr Acylic Acid & 9gr 2-proponal & 50gr Water
ϵ_r
Frequency (GHz)
$\times 10^9$

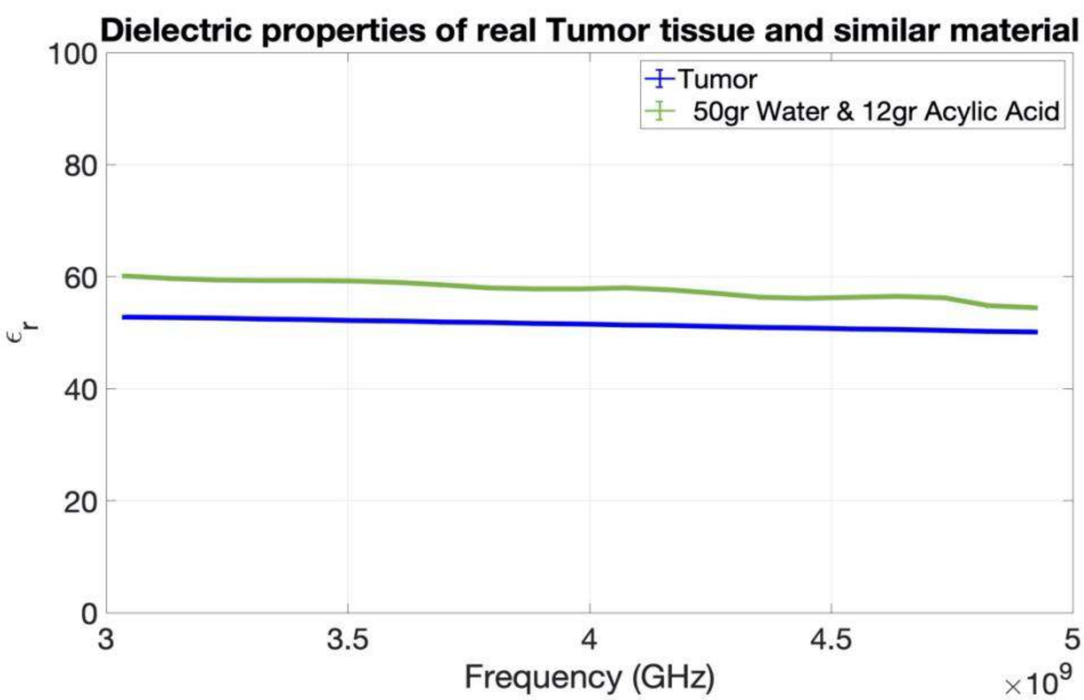
(a)


Dielectric properties of real Fat tissue and similar material
Fat
2-proponal
ϵ_r
Frequency (GHz)
$\times 10^9$

(b)



(c)



(d)

Figure 2.2: (A) Relative permittivity comparison between gland breast tissue and a mixture. (B) Comparison of relative permittivity for fat breast tissue and mixture. (C)Comparison of the relative permittivity of mixture and skin breast tissue. (D) Comparison of relative permittivity for tumor breast tissue and mixture.

2.3 INVESTIGATING EMPIRICAL METHODS

Analysis of the equations that offer an estimate of the permittivity created by mixing different quantities of different materials varies on volume. These equations may provide an estimate of the permittivity. Since the beginning of this century, other tests have made use of these equations. In 2012, a group of researchers attempted to determine the dielectric characteristics of a combination of rice husks and rubber tire dust that would be used in a microwave absorber. However, the findings did not match the actual material. Nevertheless, it was an assessment that may be considered credible [39].

After going through all of those calculations, we have arrived at three distinct formulae that have the potential to yield a permittivity that is rather near to the actual observed value. The computed permittivity for three alternative equations is shown in Figure 2.2. These equations account for different mixing ratios than the data that was observed. Begin with formamide at 75 % and mono propylene glycol at 25 %, then go on to formamide at 50 % and mono propylene glycol at 50 %, and then finish with formamide at 25 % and mono propylene glycol at 75 %. When the equations are applied, as well as when the permittivity of the percentage mixes is calculated, the results that each formula produces are distinct. When compared to the actual data, the Kraszewski equation (Eq.2.1) displays a much greater error percentage than the other equations do. The Landau equation (Eq.2.2) came in second place, and while it had a lower error rate than the Kraszewski equation, it was still far off from the outcomes that were desired. Lastly, the Lichtenecker equation (Eq.2.3) provides the most accurate estimate of permittivity out of all the equations, but it does deviate very little from the actual data that was observed. Table 2.2 was created as a result of comparing all of the permittivity values that were obtained from the various mixtures and formulas with the actual data that was measured. This comparison resulted in the creation of Table 2.2, which displays the total percentage error for each equation when using different amounts of mixtures [39].

Kraszewski equation:

$$\sqrt{\varepsilon *}= \sum_{i=1}^{n} \upsilon i \sqrt{\varepsilon i} \quad \textit{Equation} \qquad (2.\ 1)$$

Landau, Lifshitz, and Looyenga (Landau equation):

$$\sqrt[3]{\varepsilon *}= \sum_{i}^{n} \upsilon i \sqrt[3]{\varepsilon i} \quad \textit{Equation} \qquad (2.2)$$

Lichtenecker equation:

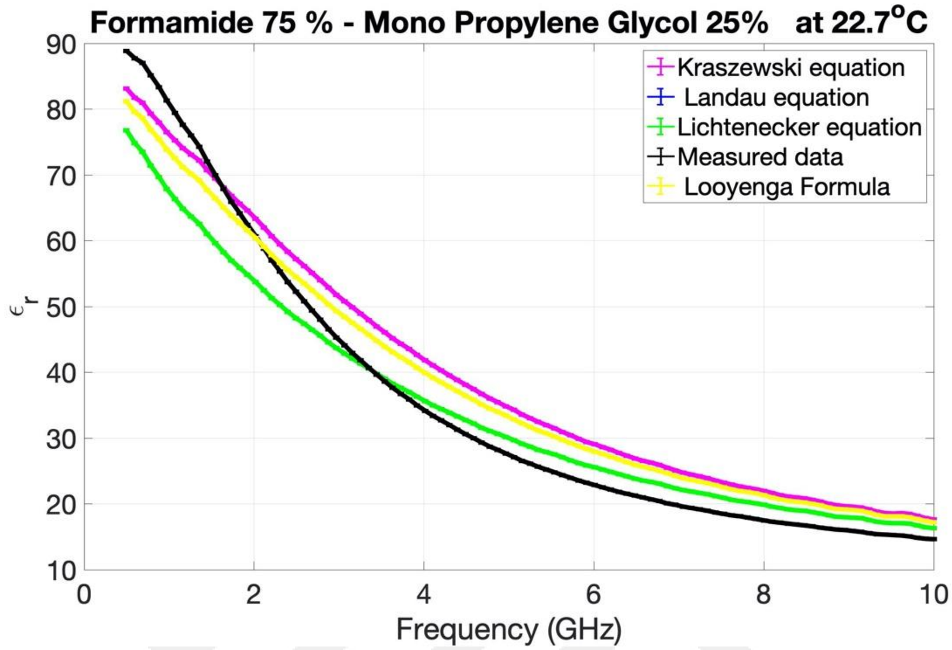
$$In\varepsilon * = \sum_{i}^{n} \upsilon i\ In\varepsilon i \quad Equation \qquad (2.3)$$

Where υi = volume fraction of the ith constituent

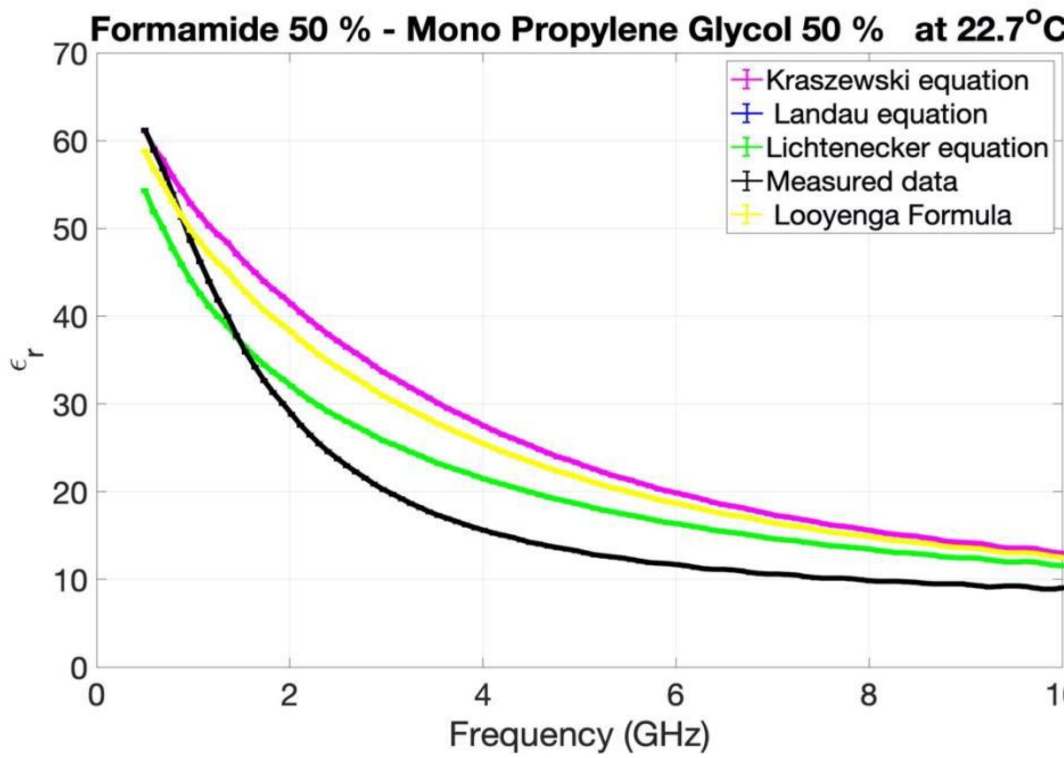
εi = permittivity of the ith constituent

n = number of constituents in the sample

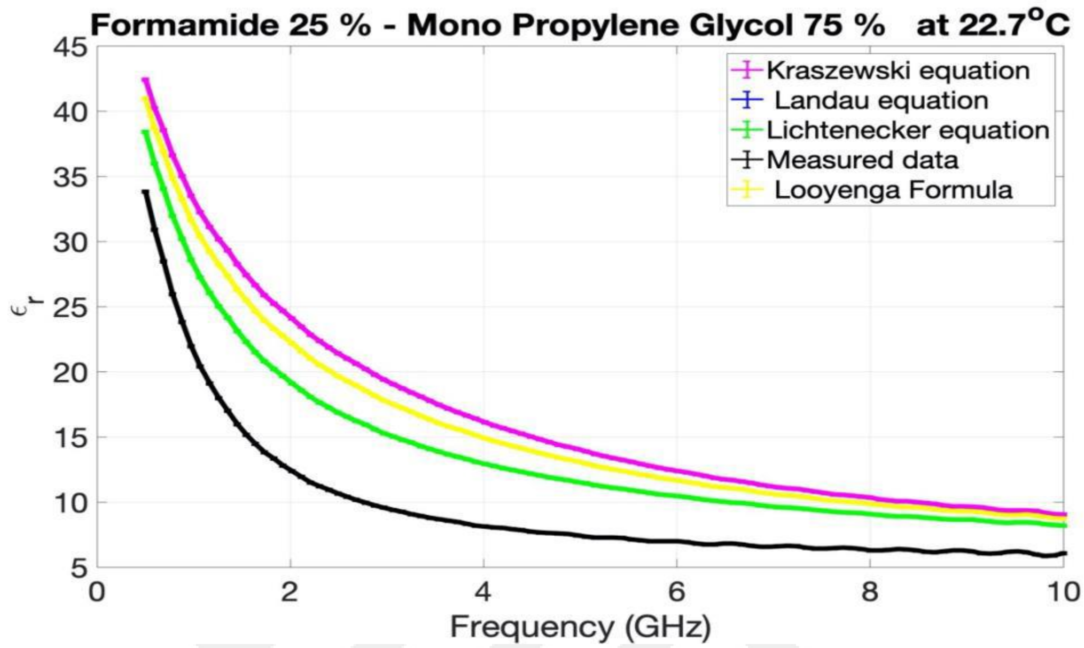
$$total\ volume\ fraction, \sum_{i}^{n} \upsilon i = 1.$$


Formamide 75 % - Mono Propylene Glycol 25% at 22.7°C
Kraszewski equation
Landau equation
Lichtenecker equation
Measured data
Looyenga Formula
ε r
Frequency (GHz)

(a)


Formamide 50 % - Mono Propylene Glycol 50 % at 22.7°C
Kraszewski equation
Landau equation
Lichtenecker equation
Measured data
Looyenga Formula
ε r
Frequency (GHz)

(b)



(c)

Figure 2.3: Illustrate the comparison between five different equations for permittivity estimation (A) shows the estimated permittivity for Formamide 75% and mono propylene Glycol 25 % (B) indicates the estimated permittivity for Formamide 50% and mono propylene Glycol 50 % (C) indicates the estimated permittivity for Formamide 25% and mono propylene Glycol 75 %.

Table 2.2: Shows the error percentage between each equation and the measured data.

Percent difference for each equation	**75%**	**50%**	**25%**
Kraszewski equation	19.3	56.2	76.2
Landau equation	16.0	46.8	65.3
Lichtenecker equation	10.5	30.0	47.6

2.4 MEASUREMENT SETUP AND PROCEDURE

The measured data were acquired with the use of a commercial Agilent thin form probe kit and the N5230A PNA Series Network Analyzer, all of which were controlled by the 85070E software. The aperture diameter of the probe is 2.2 mm. The sensing depth of the custom probe was reported to be between 0.75 and 1.5 mm when it was used on inhomogeneous materials [40], and when it was used on slender forms, the probe reported between 1.05 and 1.41 mm [41]. Agilent 20 GHz flexible RF wire was used in order to make the connection between the probe and the analyser. During the measurements, a stand held the probe, and the sample was brought up to the point where the probe was pointing. Before any measurement, a short, open, and distilled water calibration was made to the probe kit by following the standard calibration procedure [42].

Known liquids were utilized to validate each calibration once it had been completed. Due to their well-known dielectric characteristics in the literature, methanol and 0.1 M NaCl solution are utilized [43]. To get findings that were comparable to the permittivity of the breast tissues, several combination ratios had to be made in this experiment. Five additional measurements were also obtained at various times throughout the experiment. The average of them yields more precise data by eradicating any analysing problems that may have arisen throughout the experiment, such as probe mismatching, vibration, and temperature variations. Because the experiment had to be conducted at room temperature, controlling the temperature of the materials was also difficult. The setup and process for measurements are shown in Figure 2.3(a), (b) and (c).

(a)

(b)

Figure 2. 4: (A), (B) illustrate the procedure and measurements set up for testing the dielectric properties of chemical materials.

2.5 RESULTS AND ANALYSIS OF THE PHANTOM

The goal of the research presented in this chapter is to investigate new materials that have the potential to exhibit dielectric characteristics that are comparable to those of oil and water. In the first step of our investigation, we analysing nine materials by comparing their permittivity, conductivities, and boiling temperatures. According to the results, there are three to four different materials that have the potential to tolerate oil and water during phantom construction. The materials have high boiling points, which is another one of their many benefits. For example, dimethyl sulfoxide has dielectric qualities that are comparable to those of water; all that was required was some modification of the dielectric properties by the addition of other materials. In addition to that, in contrast to water, it has a much higher boiling point.

We were ultimately successful in developing a new material that has a high boiling point and may be used for phantom creation in a more effective manner. A phantom that is very appropriate for use in hyperthermia applications and a phantom that has a shelf life that is much longer are both able to maintain temperatures that are higher than the fundamentals.

The discovery of a formula that may be used to approximate the dielectric characteristics of a mixture is the second objective of this chapter. In order to look into this matter, we were required to test five alternative equations. We conducted the experiments using three distinct combinations of the materials. In each combination, there are two additional components that are present in varying proportions. According to Table 2.2, the Lichtenecker equation provides a reasonable approximation of the real-world observed data with a small amount of margin for error. In comparison, the Kraszewski equation has a poor matching with the actual observed data and has a significant amount of inaccuracy in its calculations.

3. ANTENNA DESIGN

3.1 INTRODUCTION

Experimental studies conducted over the last 10 years have shown that the addition of hyperthermia results in a significant improvement in the treatment of malignant tissues in conjunction with either radiation therapy or chemotherapy [44, 45]. The heat is one of the most important aspects of the hyperthermia therapy, and because of this, the temperature of the tumor within the human body has to be kept between 40 and 45˚C for a few minutes. Ultrasound and the use of electromagnetic waves are two distinct approaches that may be taken to raise the temperature of the body. According to the traditional model, a tumor is assumed to be situated in a somewhat deep place. In this scenario, the treatment is carried out by an applicator, which is comprised of a ring-shaped array of antenna elements including a variable number of antenna elements. The temperature may be adjusted to be just right for the tumor by varying the phase and amplitude of the antenna. The majority of the systems that have been created for the treatment of deep hyperthermia operate at a single frequency of around 100 MHz [46, 47].

The systems that have been shown comprise many antennas that are able to operate throughout a wide frequency range. This provides the system with the capability to build the SAR distribution in the treated region.

It has been shown in a clinical setting [48] that a tumor in the head and neck area may be properly heated by an applicator that operates at 900 MHz. When increasing the number of antennas in an applicator from 12 to 20, according to research carried out by the same group that published [49], it was found that. It enhances the transmission of heat to a particular region of the tumor, such as the nasal cavity [50].

The studies that have been described provide a parameter for treatment planning that may be thought of as the ideal frequency. It is possible to employ a certain frequency for each tumor site, as well as for each patient. Each therapy requires for a unique use of the available operational frequencies. High frequencies are utilized to treat tiny tumors because they reduce the size of the location that has to be treated. In addition, the low frequencies are used in the treatment of large and deep malignancies. In addition to this, it is very important to position the antennas in such a way that they are able to radiate in the region that is wanted.

In this work, an antenna element is given the appearance of being an element in an array. An antenna is seen to be acceptable for use in such a system if it has the following characteristics: it must be directional, its reflection coefficient must be more than -15 dB, it must have a small size, and its emission pattern must be symmetrical. In most cases, the antennas, like the ones in [50, 51], are rather big. The bow-tie is a kind of antenna that is recognized for its ability to create directed radiation patterns despite its compact size.

We mimic the Bow-tie antenna by corrugating surface and curving the radiating antenna arms. The antenna was modelled in Computer Simulation Technology (CST) software to radiate in the direction of stratified breast tissue, as was the intended direction of radiation. A cooling device in the form of a water bolus was also included into the design.

In hyperthermia, a temperature-controlled circulating water bolus is used to couple electromagnetic energy into the patient and to control the skin surface temperature. Furthermore, it can be used as the immersion medium in order to decrease the size of the antenna.

3.2 FIRST BOW-TIE ANTENNA DESIGN

When calculating the size of the Bow-tie antenna, we took into account the fact that it would be operating in a medium that is lossy. Corrugations and shorting pins were included into the design of the Bow-tie antenna so that the overall size of the symmetrical antenna could be reduced even more. These two methods are used on a regular basis in order to achieve an electrically more expanded structure. Because it is necessary to increase the number of antennas around the breast tissue in order to accomplish deep tissue heating, the depreciation of the antennas is an extremely important consideration. Figure 3.1 depicts a view from the top to the antenna, along with its final dimensional.

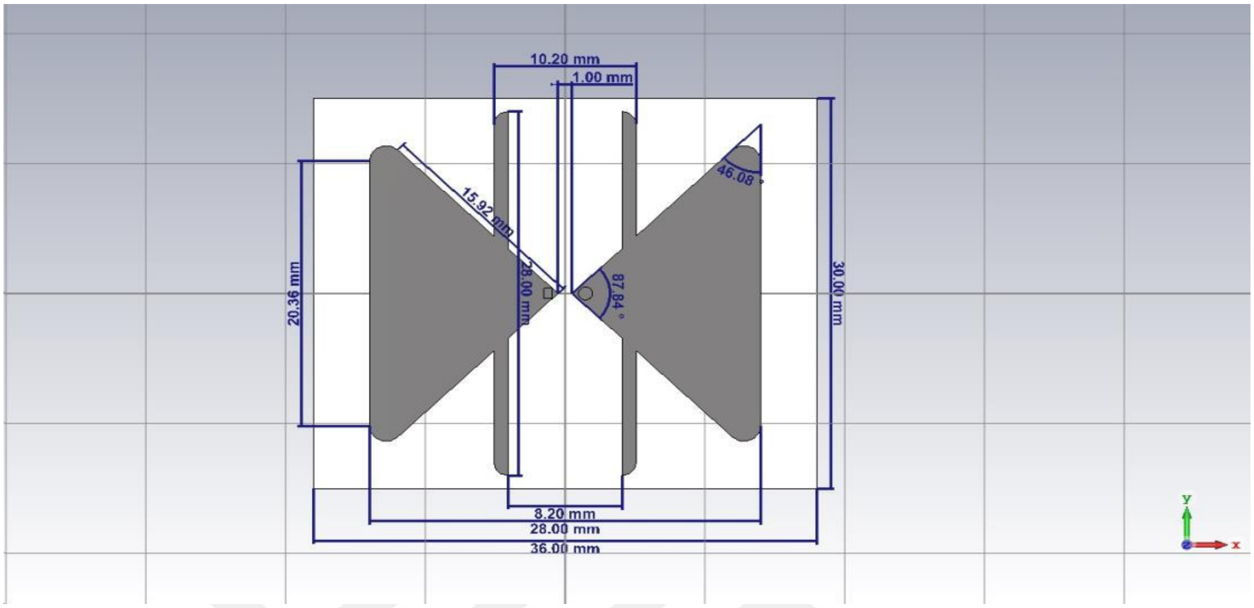


Figure 3.1: a view from the top to the finished Bow-tie antenna that has been made to radiate toward lossy tissue.

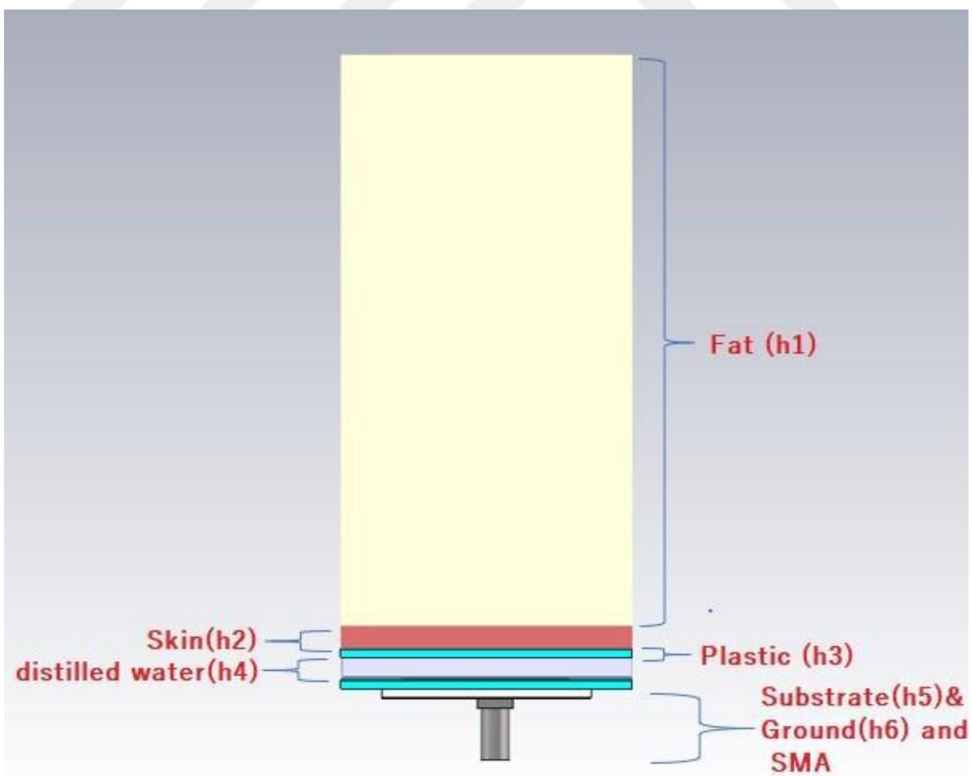


Figure 3.2: Model of a bow-tie antenna radiating towards a layer of skin, fat, and distilled water.

Table 3.1: Shows each layer's dielectric characteristics and height.

Layer	Permittivity	Conductivity (s/m)	Height(mm)
Fat(h1)	1	1	100.0
Skin (h2)	1	1	4.0
Plastic (h3)	2.8	0.01	1.5
Distilled water(h4)	78.4	1	4.0
Substrate (h5)	2.2	1	1.6

Two pin was used in order to complete the ground plane to antenna patch components short circuit. Because of the effect that these pins have as an impedance or capacitance, the antenna is able to radiate at a low frequency. These design ideas allowed for a reduction in dimensions that was 50% less than before. The design of the antenna may be seen in Figure 3.2. It consists of the layers breast imitating phantom (fat and skin), as well as bolus of water. The dielectric characteristics of each layer in the design are outlined in Table 3.1, along with their respective heights.

It should be pointed out that the element of the antenna patch was submerged in the water bolus. The breast phantom was used to replicate the antenna in CST, where the simulation took place. Based on these findings, it can be concluded that the antenna operating within the -10db reflection coefficient. SMA was the antenna centre feeding, and a space was left between the ground and the SMA in order to distort and prevent the radiation signal.

3.2.1 Result and Discussion

The purpose of these designs is to create an antenna that is work at low frequencies (900 MHz). Additionally, the size of the antenna should be minimized to an extent that satisfies the requirements of the application. The impedance matching between the antenna patch element and the feeding line was the part of the design of this antenna that presented the greatest amount of difficulty. The response of the improved system's S-parameter is seen in Figure 3.3. The gain was very close to 0.255 despite the fact that the antenna was meant to radiate towards a medium with a high attenuation. Changing the phase of the antenna allows for a sufficient amount of control over the radiation pattern, allowing it to be directed at the tumor. The radiation of the antenna as well as its gain are shown in figure 3.4.

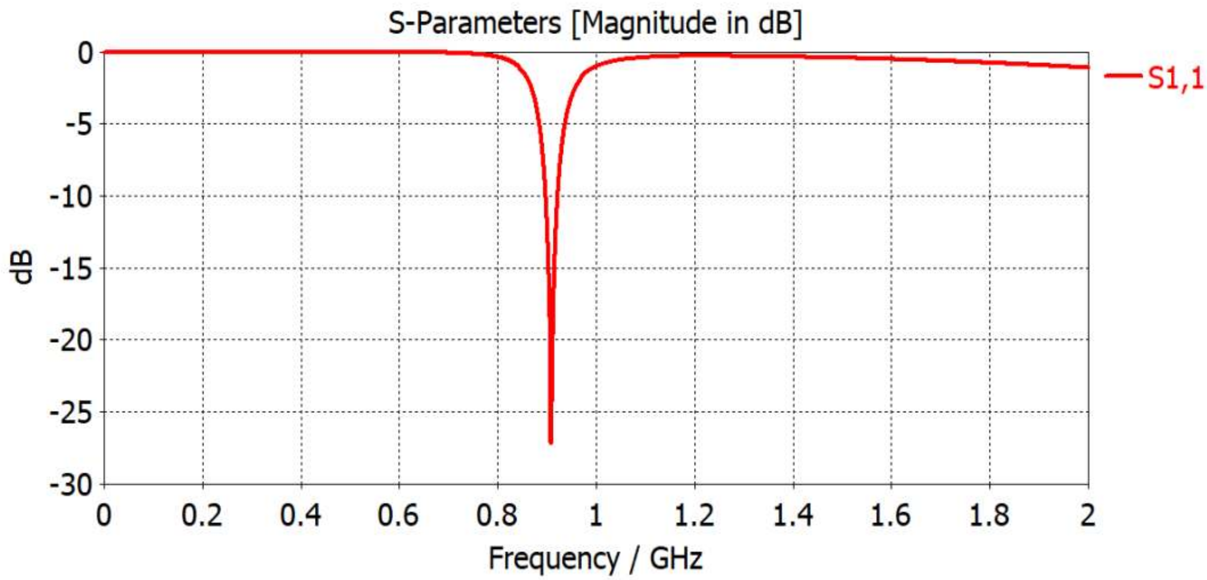


Figure 3.3: Simulated S-parameters of optimized Bow-tie antenna radiated into lose medium.

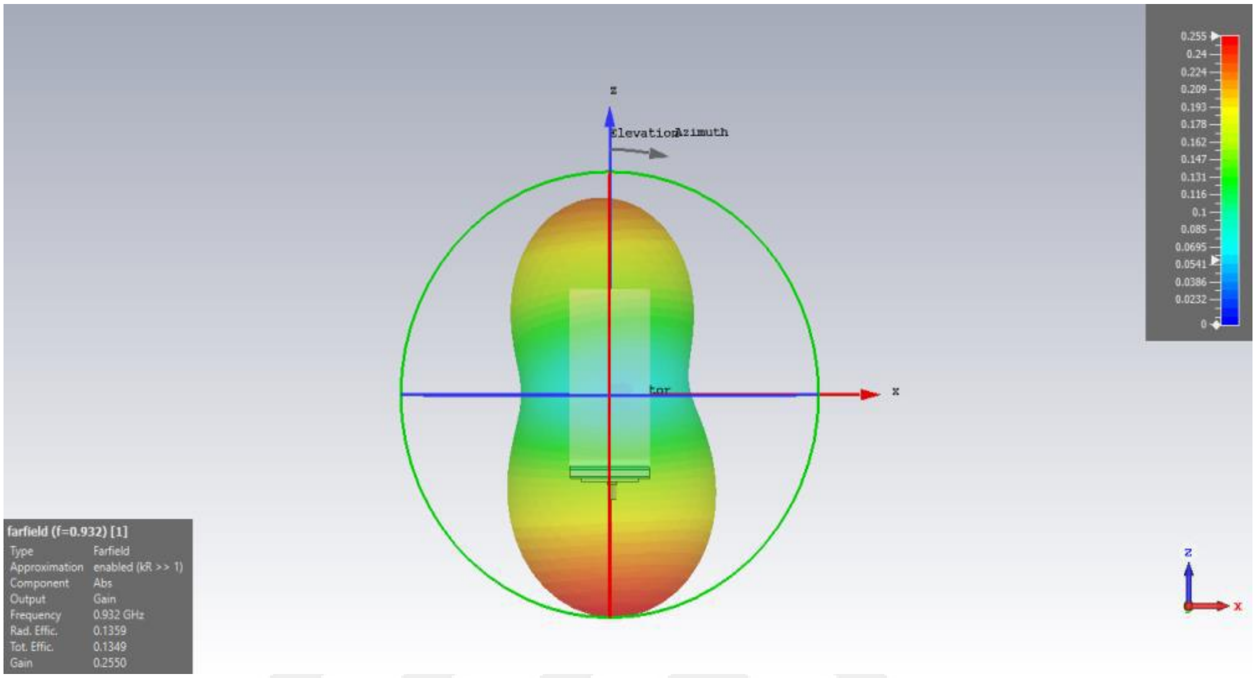


Figure 3.4: Simulate antenna radiation and gain.

3.3 SECOND BOW-TIE ANTENNA DESIGN

In this segment, we sought to concentrate on the weak spots of the earlier Bow-tie antenna designs and overcome the limitations that we had not been able to improve upon in the prior design. These limitations included the bandwidth, the antenna shape, and the operating frequency. The first step in optimizing the prior design is to take into consideration a variety of criteria. The size of the antenna itself served as our point of departure. By making use of the sweep parameter and carrying out tens of simulations, we were able to locate the dimensions that are the most suitable to satisfy our needs.

The width of the bowtie is now 30.29 mm, up from 28 mm, and the length is now 28.77 mm, up from 20.36 mm. In addition, the size and location of the corrugations have shifted from 28 mm to 29 mm and from 10.20 mm to 7 mm, respectively. As can be seen in Figure 3.5, there was also been an alteration of a certain angle made to the edge of the corrugation.

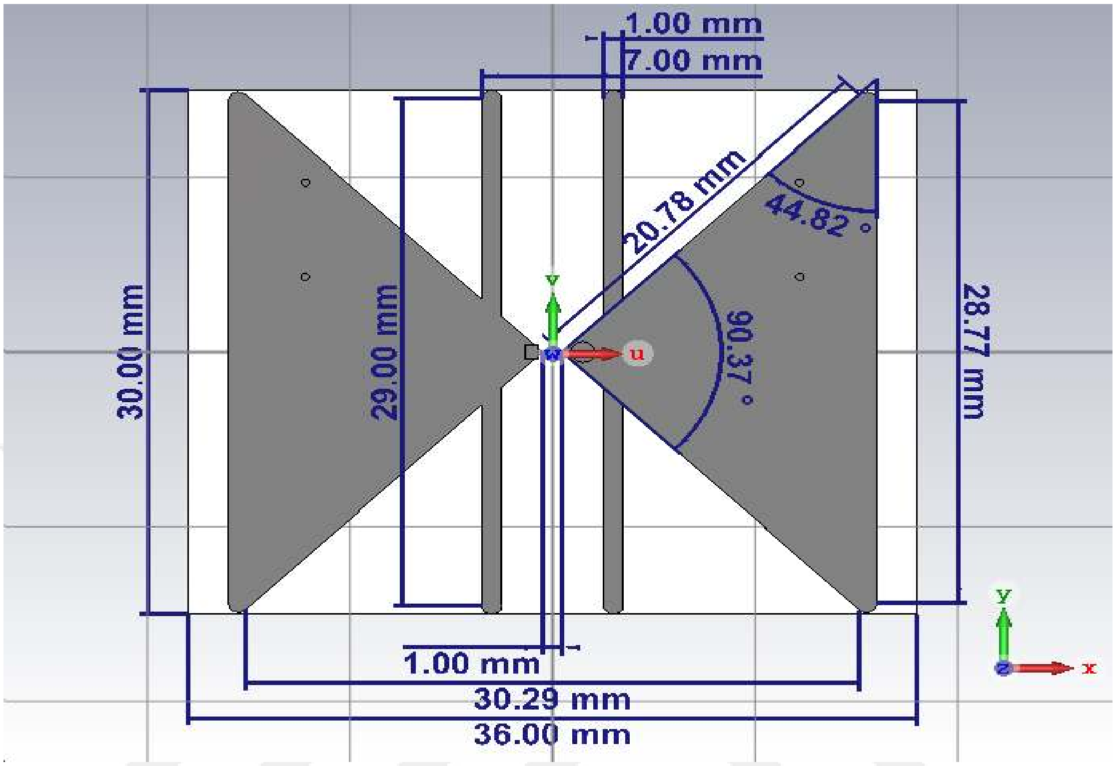


Figure 3.5: a view from the top to the ultimate Bow-tie antenna, which has been tuned to radiate towards lossy tissue.

Because of the pins' great efficacy, we attempted to build them in such a way that they would operate as an impedance. This makes it possible for the design to be smaller, the operating frequency to be lower, and the bandwidth to be larger. In this instance, each patch has been designed with a separate pair of pins (four pins in total). We had to run tens of simulations to figure out how the antenna acts with pins and what parameters can affect the effectiveness of pins because there is no specific formula that we can follow to find the best positions and number of the pins that we can use in antenna design. Because of this, we had to run the simulations.

We have come to the conclusion that when the pins are positioned such that they are close to the feeding line, it works as resistance, and this, serves to enhance the operating frequency. On the other hand, when the pins are place far from the coaxial cable, it begins to behave in a capacitance-like manner. The antenna is able to broadcast at lower frequencies as a result of this.

After reaching this conclusion, the next step is to begin evaluating how well the strategy works as the number of pins is increased. The simulations reveal that, in comparison to the other pins, only two pins (in each patch) provide satisfactory results. We were able to achieve the thin form of the ground while also having four pins, two in each patch, by making use of the sweep parameter for both the pins and the ground. The sweep parameter demonstrates that the ground's narrow profile contributes to our design in a positive way. As can be seen in Figure 3.6, this form lowers the resistance of the ground while simultaneously increases the antennas operating frequency bandwidth.

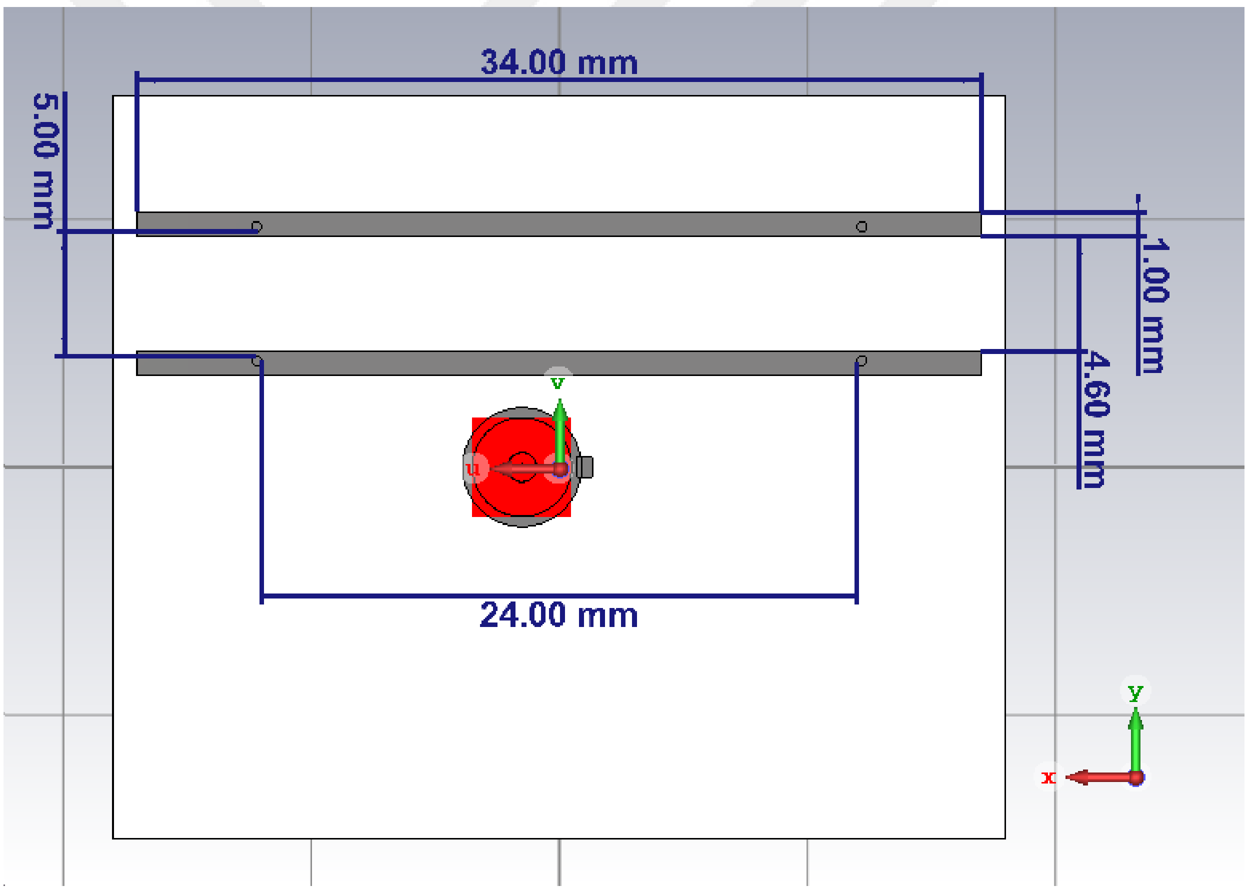


Figure 3.6: View from behind the final Bow-tie antenna that is most suited to radiate toward lossy tissue.

After optimizing the size of the antenna in accordance with the information shown in Table 3.2, we begin thinking about the substrate, the dimensions of the phantom's layers, and the materials that will be used to simulate the breast's skin and fat. There is a discernible increase in bandwidth after changing the material of the substrate from FR-4 to Rogers RT5880 as well as the breadth of the substrate. Not only has the height of the distilled water and plastic varied, but also the thickness of the Rogers has changed in order to increase the operating frequency bandwidth. This adjustment was made in order to accommodate for the increased thickness of the Rogers.

As can be seen in Figure 3.7, all of these modifications have been done using the sweep parameter in order to get the best possible outcome for our design. The addition of distilled water and increasing the thickness of the plastic covering were critical components in the process of expanding the antenna's bandwidth. Additionally, the antenna underwent testing with novel materials that fulfil the dielectric qualities of a realistic breast, such as fat and skin. As can be seen in Figure 3.8, the new plastic material that was used in the construction of this design demonstrates a considerable improvement in the antenna's reflection coefficient.

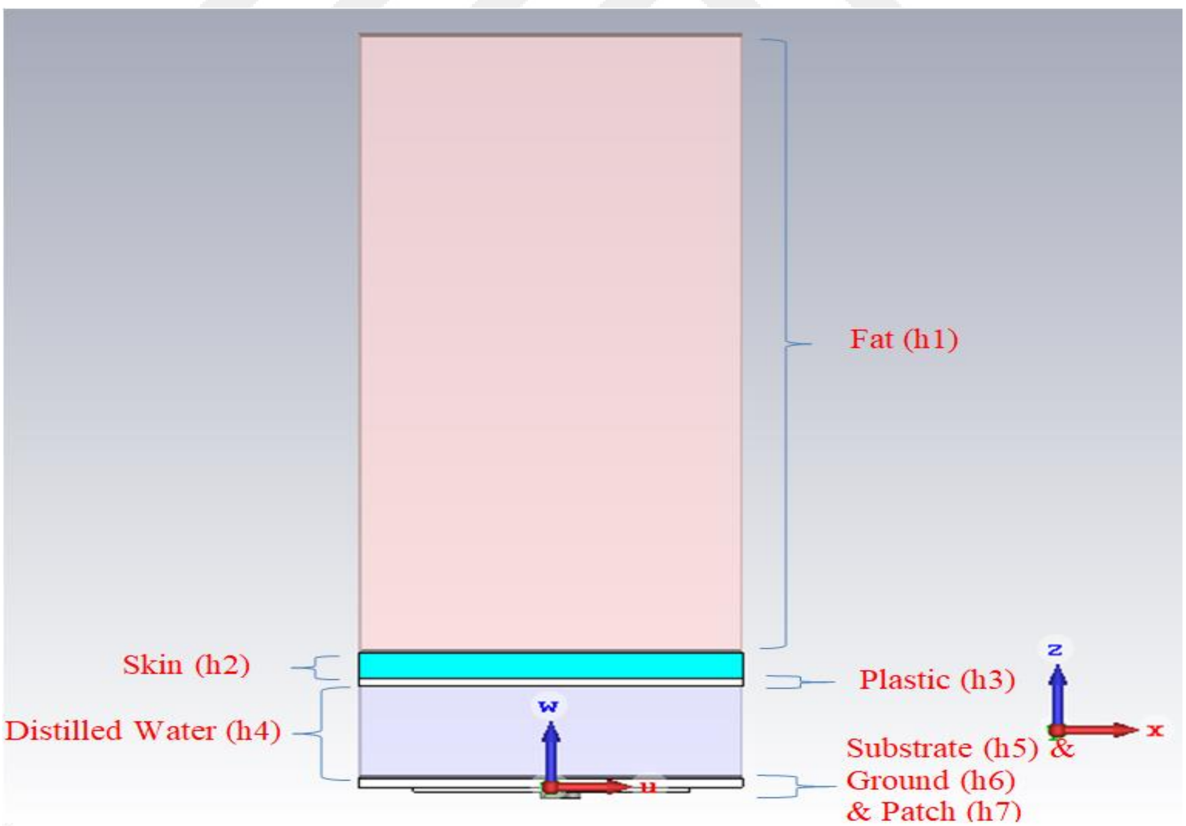


Figure 3.7: Bow-tie antenna model with skin, water bolus, and fat.

Table 3.2: Shows each layer height and dielectric characteristics.

Layer	Permittivity	Conductivity (s/m)	Height(mm)
Fat(h1)	5	0.2	100.0
Skin (h2)	38	2	4.0
Plastic (h3)	2.9	0.0	1.3
Distilled water(h4)	78.4	5.55e-006	15.0
Substrate (h5)	2.2	0.0	1

3.3.1 Results and Discussion

The major purpose of this design is to overcome the constraint that was present in the earlier design. It was operating with a very narrow band, which made it difficult to get these results in a practical way. Additionally, it was not a good antenna to be used in hyperthermia applications. Lastly, we needed to improve the directivity of the previous design and make it radiate in one direction with less loss in the energy. These challenges were presented by immersing the antenna in distilled water, fixing the operating frequency at 900MHz, improving the bandwidth because it was operating with a very narrow band, and so on.

In the new design, the antenna is better suited for its purpose and is simpler to build. For example, the antenna works across a wide frequency range and has a reflection coefficient of -20 dB while it is running at 900 MHz. Implicate the patch so that it can be easily fabricated between the substrate and the water bolus in order to boost the directivity of the antenna.

As can be seen in Figure 3.8, the reflection coefficient of the simulated antenna demonstrates that there is a big difference between the older design and the recent one. The prior design had a frequency of 900 MHz as its working frequency, with a bandwidth of 0.1 MHz. In comparison, the new design demonstrated a narrow reflection coefficient of less than -10dB while having a bandwidth of about 2.3 GHz between 800 MHz and 3.0 GHz. The S11 parameter has a value that is less than -25 dB when the required operating frequency of 900MHz is used. Because it has such a broad bandwidth, the antenna may be used in a variety of different hyperthermia applications.

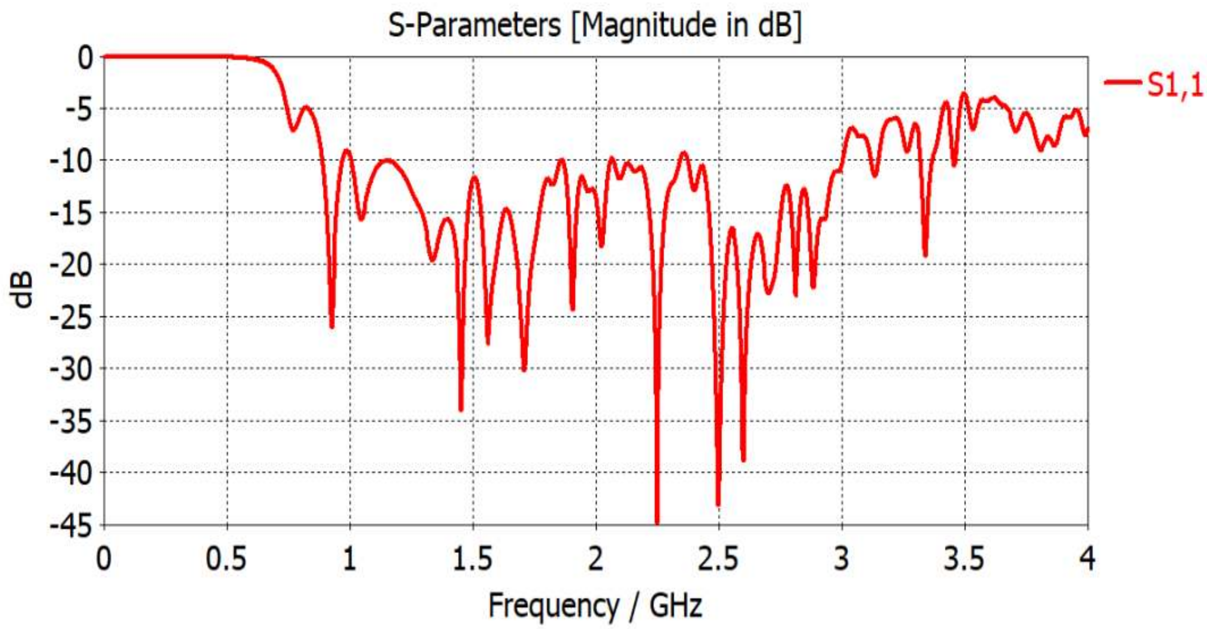


Figure 3. 8: S-parameter response simulation of the improved Bow-tie antenna radiated into the lose medium.

The gain is another aspect that was taken into consideration while developing the new design. The prior design had a gain that was low and inefficient, making it unsuitable for use in applications involving hyperthermia. Despite the fact that our new design is working in a medium that is quite lossy and has a significant water bolus of approximately 15mm, we have been successful. In comparison to the prior antenna design, this one has a gain that is 0.216. Because of this, the antenna is useful for applications involving hyperthermia. The gain of the antenna is shown in both 3D and 2D in figures 3.9 and 3.10, respectively. The polar plot illustrates the antenna's Farfield gain, which may be shown in Figure 3.11, along with the radiation pattern.

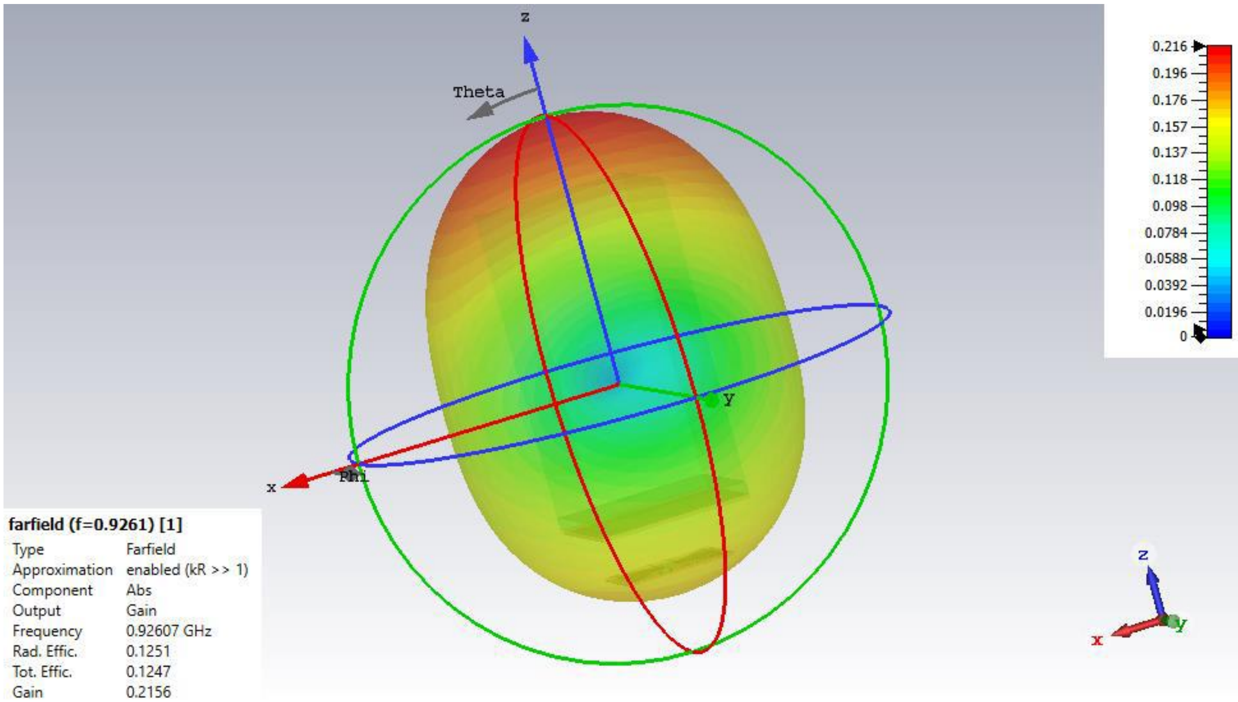


Figure 3. 9: Radiation and Gain parameters for Bow-tie antenna in 3-D simulation.

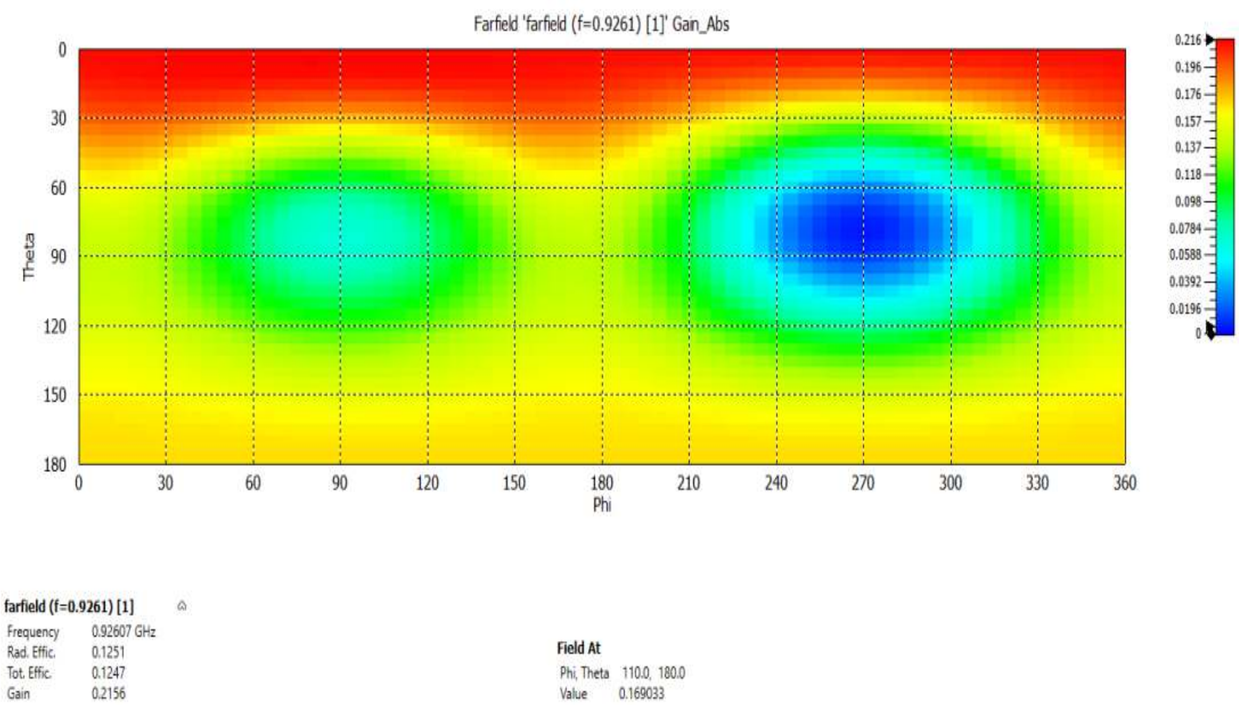


Figure 3. 10: Radiation and Gain parameters for Bow-tie antenna in 2-D simulation.

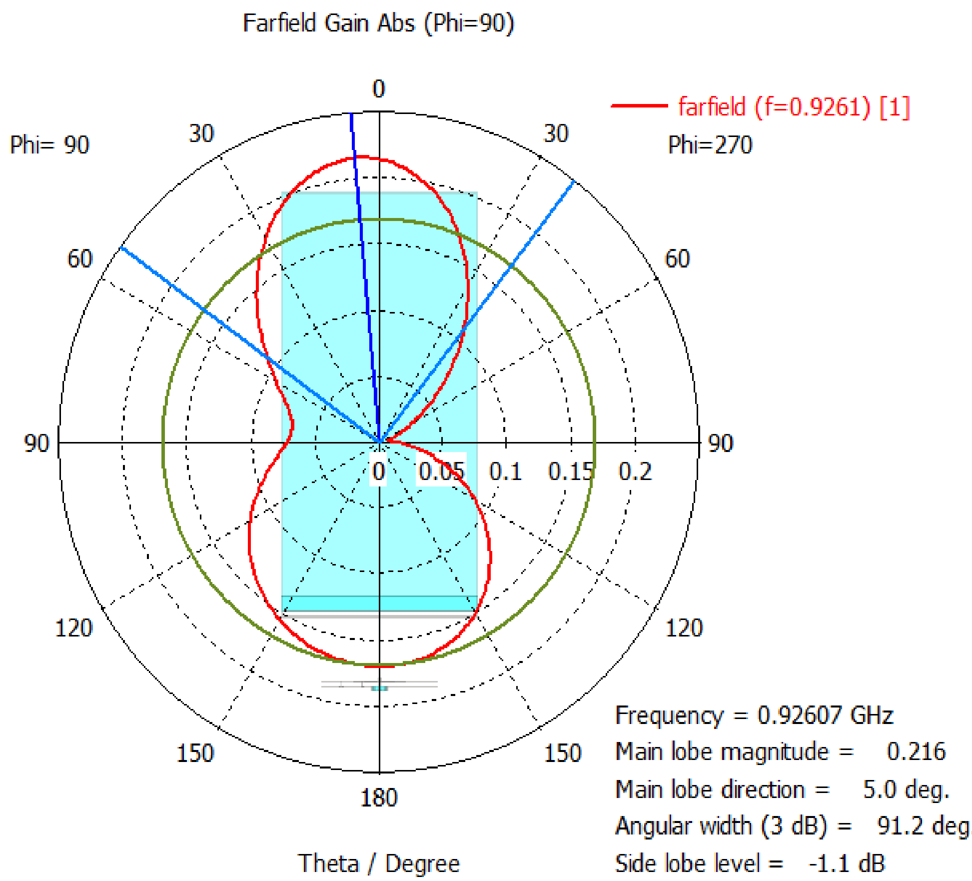


Figure 3. 11: Farfields for Gain gives the polar shape of a 0.9 GHz single-element antenna.

The directivity of the antenna and the reference impedance were the last design parameters to be examined and revised. In the work that came before, the antenna had a very low degree of directivity and did not radiate in any particular direction. The new design of the improved antenna offers a strong degree of directivity (1.72), which is important for the emission from the antenna. As a result of the vast majority of the energy sent in only one direction, the antenna is said to be unidirectional, as seen in Figures 3.12 and 3.13. As a consequence of these findings, the antenna is suited for use in hyperthermia applications. In addition to the improved directivity, the new design also has reference impedance that is almost 50 ohm, which is the same as the impedance of the feeding line. As can be seen in Figure 3.14, the matching improves the efficiency of the antenna and reduces the amount of energy that is lost.

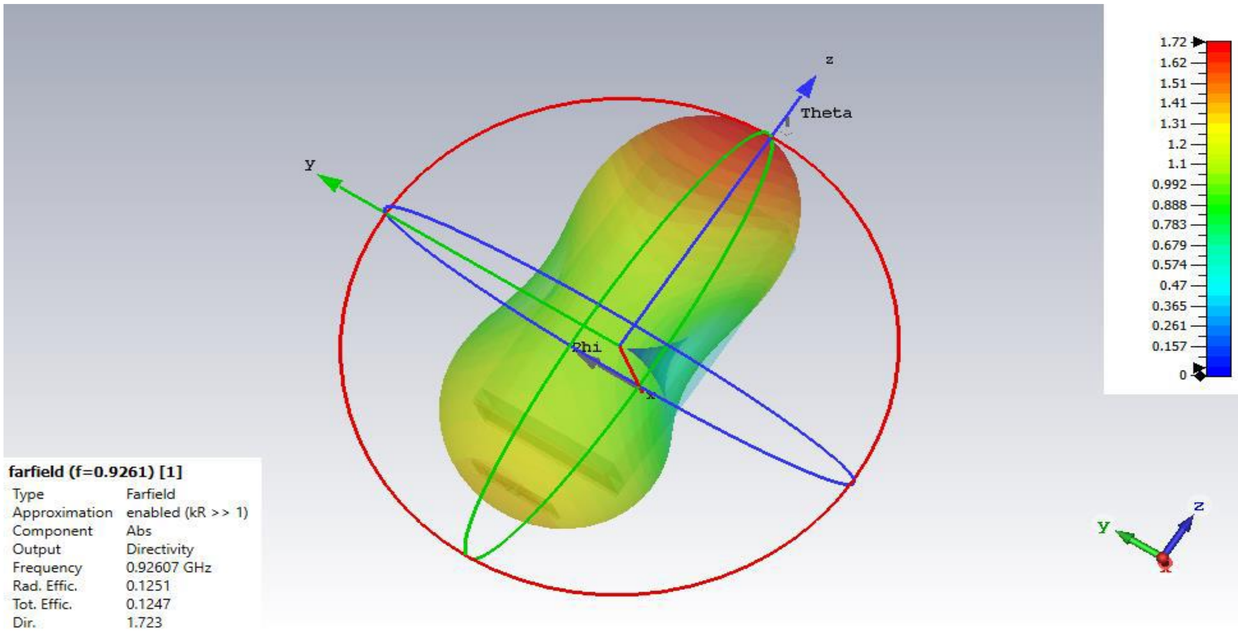


Figure 3. 12: Directivity and radiation parameters of the Bow-tie antenna in 3-D simulation.

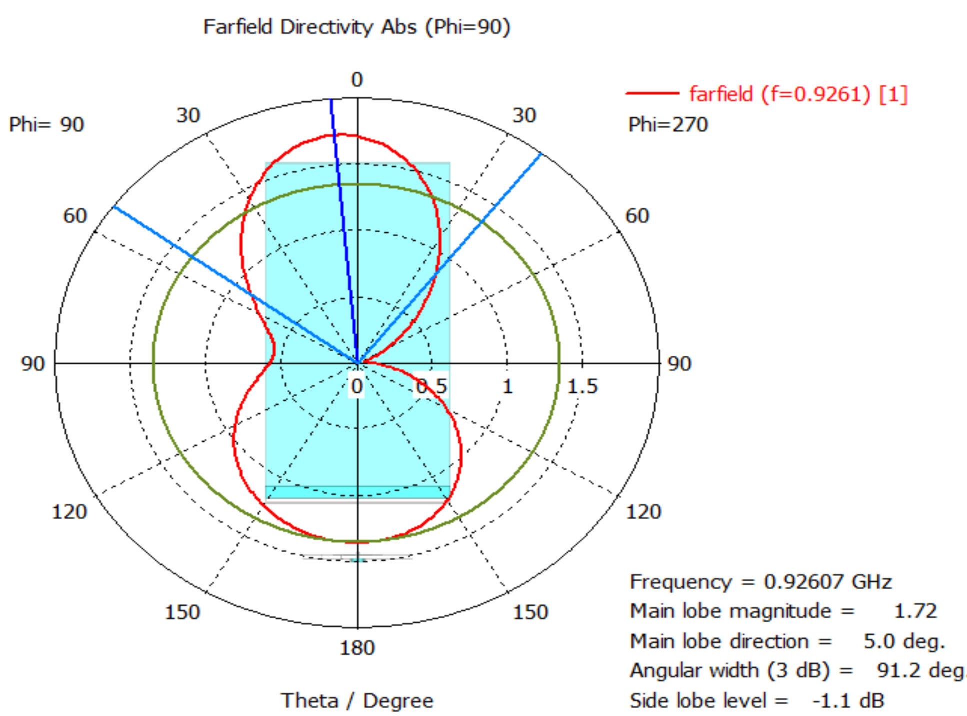


Figure 3.13: Farfields for directivity provide the polar shape of a 0.9 GHz single-element antenna.

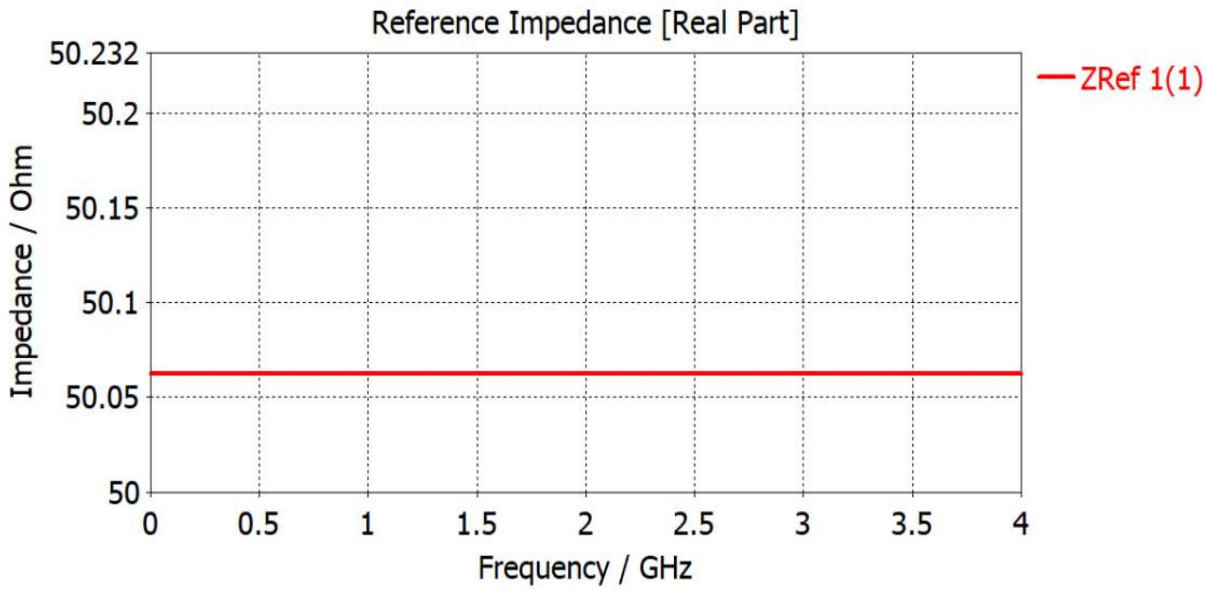
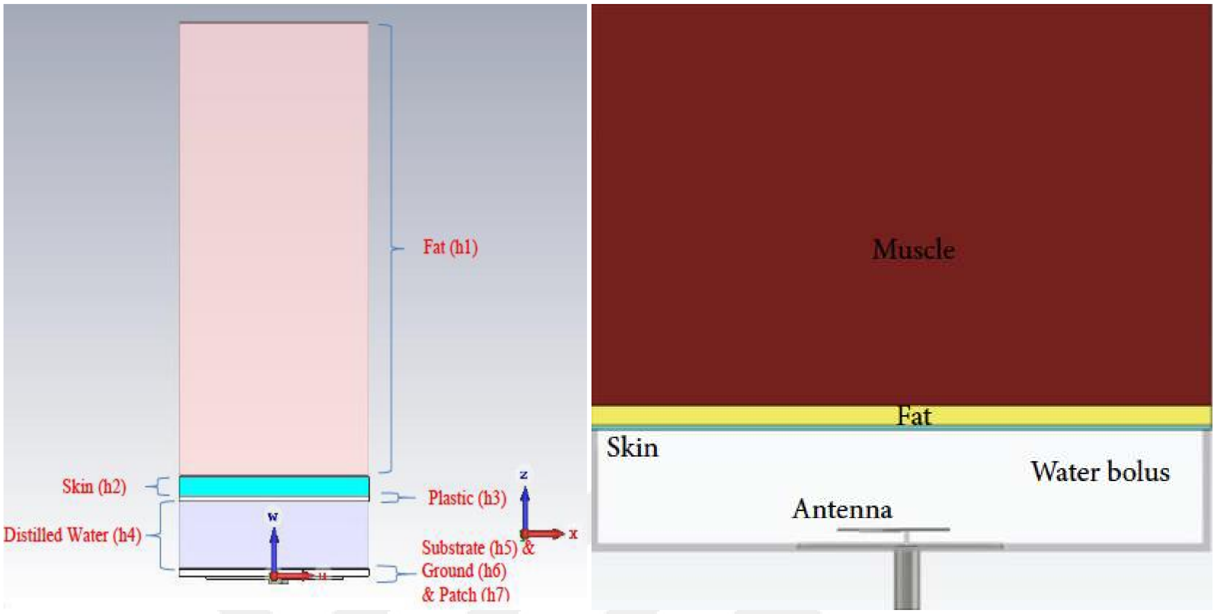


Figure 3.14: Bow-tie antenna's reference impedance.

3.4 COMPARISONS

The purpose of each piece of study is to expand and improve what has been done by previous researchers. In this part, the comparison between our design and the designs of other researchers will be the primary emphasis. Within the scope of this project, we attempted to come up with a design for an antenna that operates at frequencies lower than 1 GHz; thus, we will be concentrating on the study that focuses on the same themes. In order to evaluate the performance of our antenna in comparison to that of other researchers' designs.

The researcher in [52] attempted to develop a spiral antenna that operates at frequencies below 1 GHz by submerging the antenna in water throughout the design process. The frequency at which the antenna operates may be lowered by submerging it in a water bolus, which is the purpose of this technique. The difference between our design and the work that was published may be seen in Figure 3.15. If you look closely, you'll see that it demonstrates how the antenna was built in a model that is quite similar to our model.



(a) (b)

Figure 3.15 (a), (b): compare our work to published work.

According to the findings of [52], the spiral antenna emits electromagnetic waves at a very low frequency, which is approximate 450 MHz. This is the frequency that we want to achieve. The bandwidth limitation is the only problem with the findings. It is close to 25 MHz, and this bandwidth, which is a bit crucial in each design due to the difficulty of implementation and get the right results, as well as the restriction of the application that the antenna might use for. On the other hand, our antenna works in the range of 2.3 GHz and does not need the antenna to be immersed in a water bolus in order for it to work properly. This makes it simple to print and implement. Look at figure 3.16.

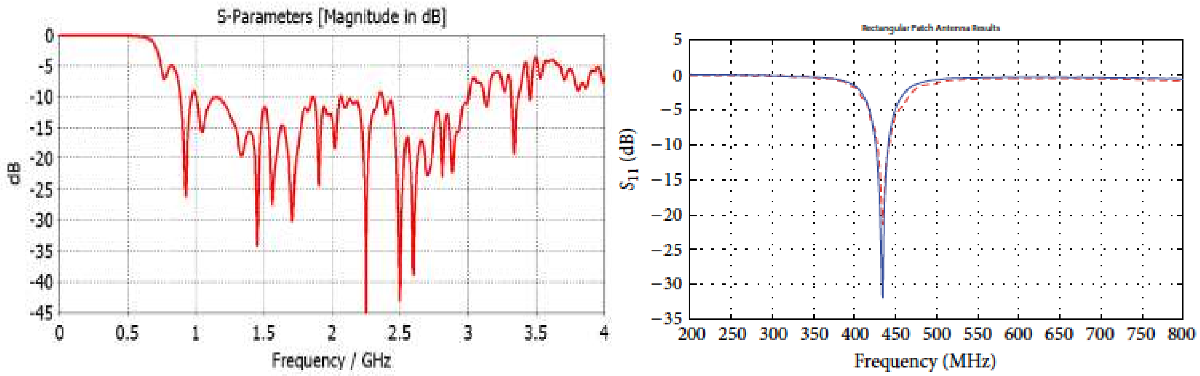


Figure 3.16: shows the S11 parameter for both our design and the published work.

Other researchers, such as those cited in [15], used a bow-tie antenna for the breast hyperthermia application. The purpose of the work that has been published is to enhance a self-grounded Bow-tie antenna by optimizing the width of the radiating section and the thickness of the pins. Additionally, sweep parameters were employed in order to optimize the thickness of the pins. See figure 3.17.

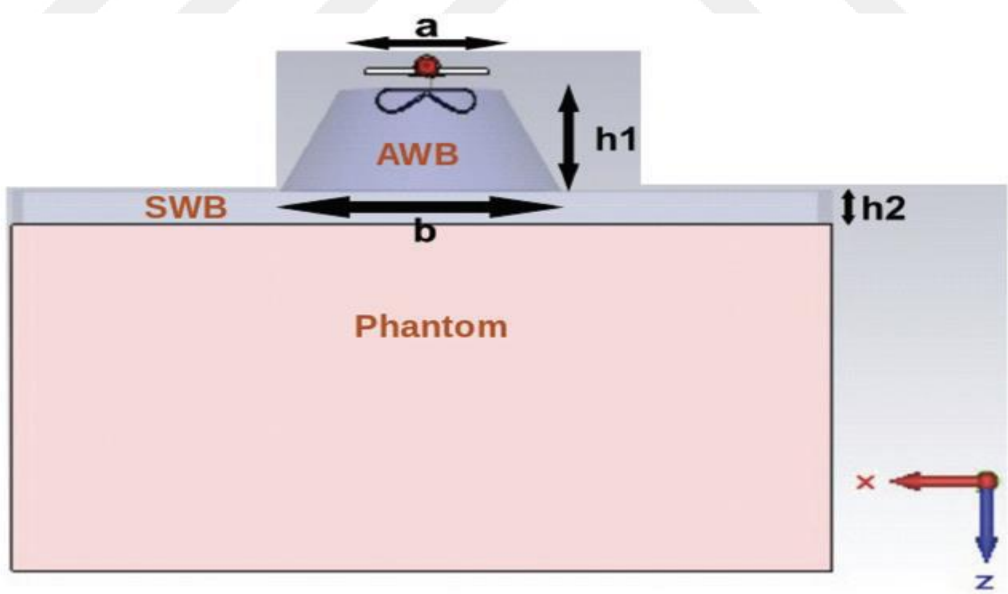


Figure 3.17: illustrates antenna in a lossy medium

In addition to this, the antenna was submerged in a water bolus for a period of time. They were successful in developing a design for an antenna that has a range of 200 MHz bandwidth and works at 0.7 MHz. The simplicity of our approach together with the greater breadth of the available bandwidth gives it an edge over competing design. See table 3.3 to have a better understanding of the changes in performance that exist between the various antennas.

Table 3.3: Shows the main differences between the compared antennas.

Antenna	Operating frequency	Bandwidth	Antenna immersed
Our design	900 MHz	2.3 GHz	No
Antenna[52]	450 MHz	25 MHz	Yes
Antenna [15]	0.7 MHz	200 MHz	Yes

In conclusion, this comparison demonstrates that our research has resulted in the development of an antenna that is suitable for use in a wide variety of applications due to its low operating frequency, small size even when operating in a lossy medium, ease of implementation, and broad bandwidth.

3.5 ANTENNA ARRAY RESULTS

Using our bow-tie antenna, we made an attempt to replicate the behaviour of a group of antennas in this section. The purpose of this experiment is to determine how well an antenna can operate around a simulated breast. We constructed a cylinder shape with multiple layers to imitate the breast tissues, and then we encircled it with a series of antennas. For more information about the layers, check table 3.4. When building an antenna array, various applications have thought about using a variety of different numbers of antennas [53, 54]. We were forced to design a set of six antennas because to the size constraints of the breast, with each antenna being spaced apart from the others by 60 degrees. See figure 3.18.

Table 3.4: displays the breast's size, the water bolus's thermal and dielectric characteristics.

Layer	Relative permittivity	Conductivity (s/m)	Thermal Conductivity	Heat capacity	Density	Outer radios(mm)	High(mm)
Fat	5	0.2	0.21	2.3	911	50.0	200
Skin	38	2	0.37	3.3	1109	4.0	200
Plastic	2.9	0.0	0.19	1.2	1200	1.3	200
Distilled water	78.4	5.55e-006	0.6	4.2	998	15.0	200

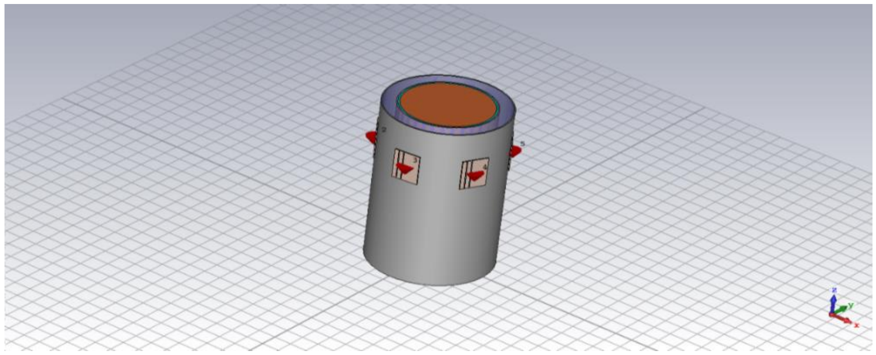


Figure 3.18: shows the set of antennas on the breast.

The findings indicate that the antenna may work in a variety of environments provided that the specified design features are taken into consideration at all times. We did not alter the phase of the antennas in order to get these findings, and the amplitude is the same for each port. See figure 3.19.

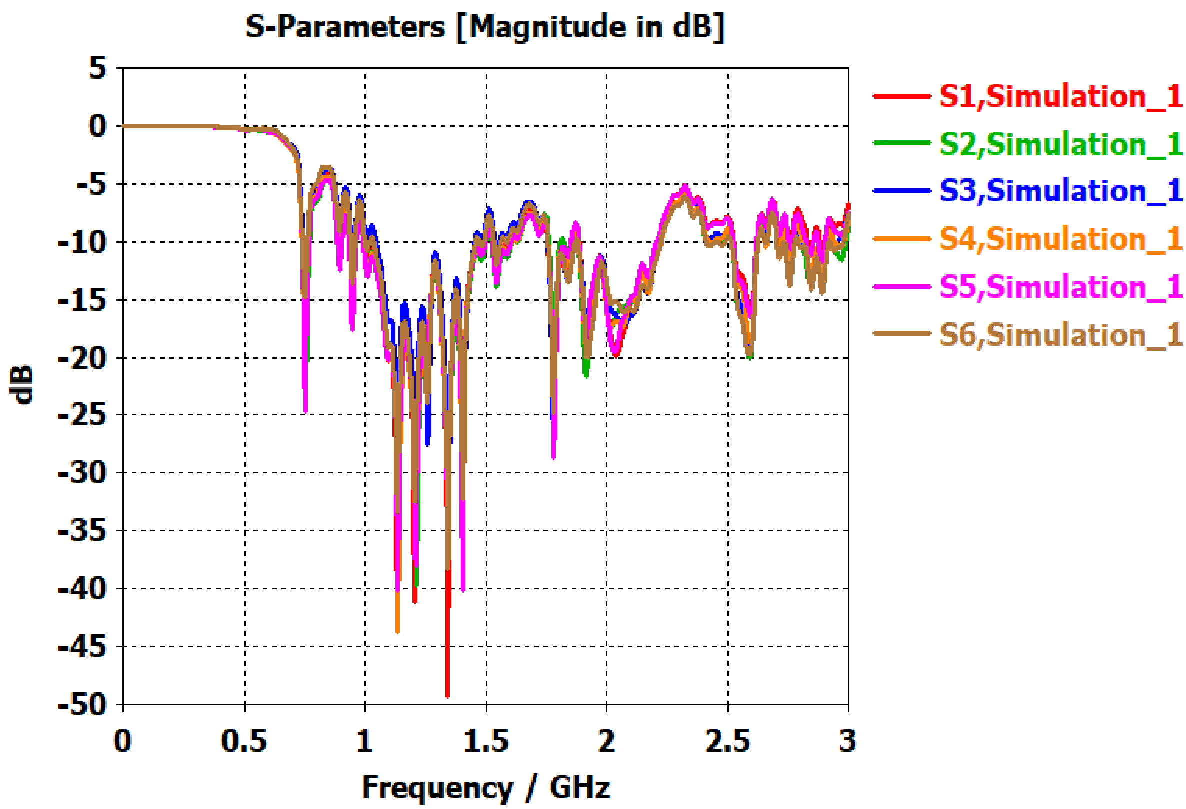


Figure 3.19: S-parameter for a set of antennas around breast

The power loss density and the SAR are two additional parameters that need to be taken into consideration. Take a look at figures 3.20 and 3.21 at the same time. In order to determine whether or not the antennas are able to radiate and heat the breast at a certain frequency, it is necessary to do an analysis of these parameters.

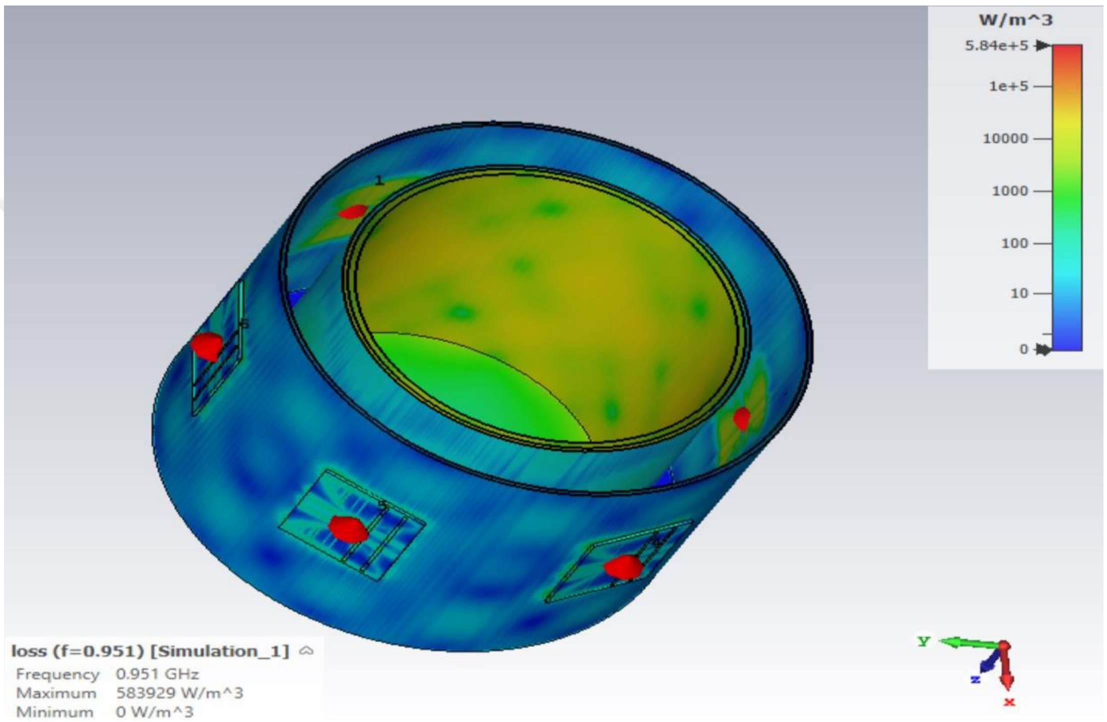
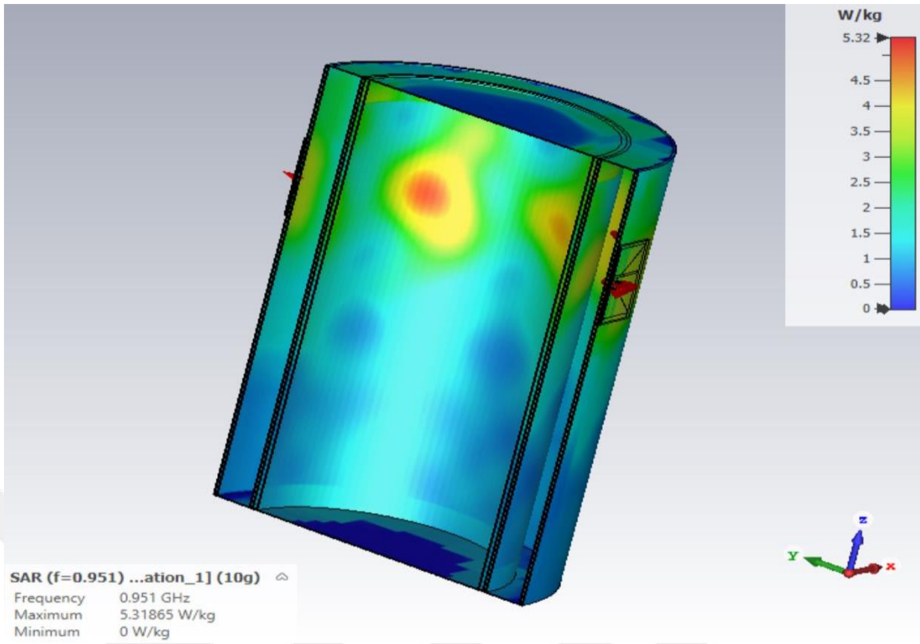
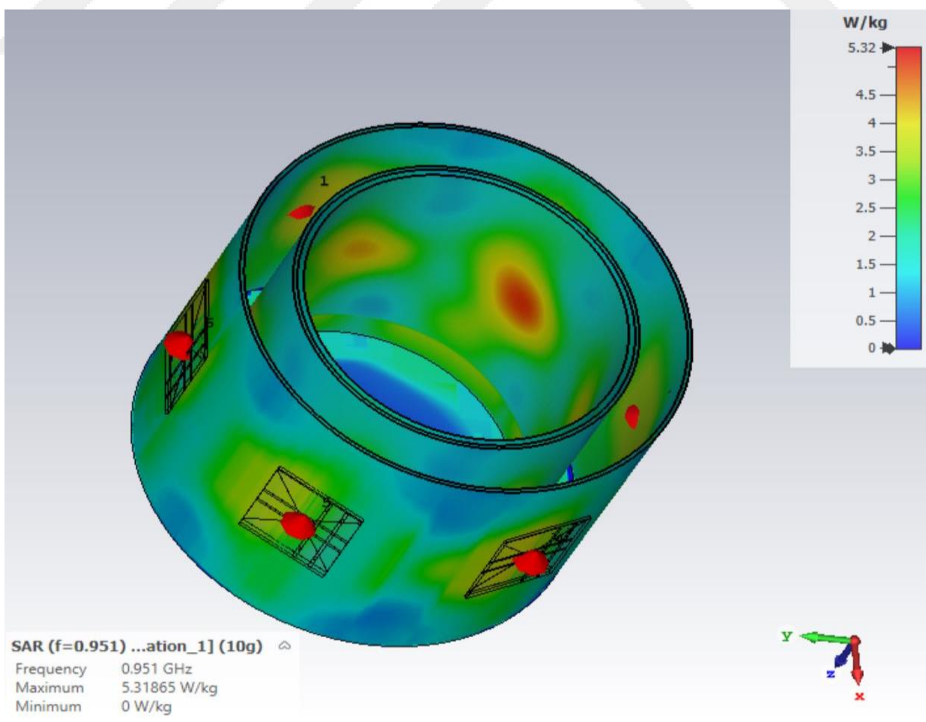


Figure 3.20: Show the array of antennas around the breast's power loss density.

In figure 3.20, an array of antennas has been placed around a cylindrical shape that mimics the Cole-Cole parameters of women breast. The idea of this simulation is to have a better understanding of the behaviour of the antennas array in real practical experiment. The findings show a promising result that can defiantly be taken to the lab experiment and test the antenna with a phantom. Due to that we have made a set of tests to have a phantom that can handle the temperature of out antenna and eventually we might be able to heal some breast tumours without a surgery. The above picture shows as well smooth distribution of the antennas array around the breast.



(a)



(b)

Figure 3.21: (A), (B) the SAR of the antenna array around the breast.

In figure 3.21(A, B), the SAR results are shown as well around the breast, the cylinder shape made with the same characteristics of the female breast specially with the Skin, Gland and Fat. Therefore, according to the about results we can start print the antennas and create the phantom to a more practical test.

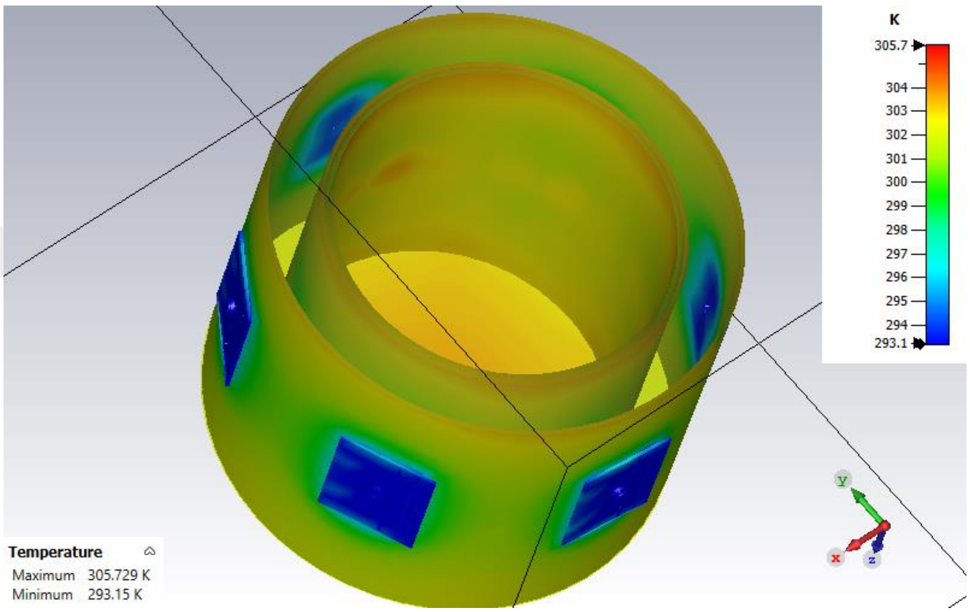


Figure 3.22: the distribution of temperature inside the breast.

Lastly, we put the EM-thermal simulation project through its paces in CST so that we could examine the temperature distribution throughout the simulated breast. See figure 3.22.

4. CONCLUSIONS AND FUTURE WORK

Throughout this effort, we provided two sets of findings. The production of phantom materials contributed to the initial set of findings. In this part of the process, the goal is to locate materials that have a permittivity and conductivity (Cole-Cole parameters) that are comparable to water and oil but have higher boiling points. This will ensure that the new phantom can withstand higher temperatures for a longer period of time without losing its quality. After that, we begin the process of looking at equations that may be used for permittivity estimation by using five formulae for three mixes. Each of these mixtures is created by combining two components in varying proportions. The findings indicate that the Lichtenecker equation provides a permittivity that is quite near to the actual value that was observed. From this point forward, we are able to begin using the Lichtenecker equation as an estimating equation for any chemical combinations that we may encounter. Reproducing the dielectric characteristics of breast tissue, including the tumor, fat, skin, and gland, was another objective of the research. By carrying out a wide variety of comparison tests between the actual dielectric properties of breast tissues and the dielectric properties of other materials and combinations. The findings indicate that it is possible to reproduce breast tissues using different materials, but at lower frequency.

The second set of findings pertains to the antenna design, which has been divided into two parts: the design itself, as well as the optimization of the design. The first Bow-tie has to be able to radiate through a lossy medium (breast), have an operational frequency of 900MHz, and have a broad bandwidth. The outcomes were satisfactory enough to fulfill the criteria of our application.

In the next part of the antenna design, we will concentrate on finding a solution to the problem that we encountered with the original design. We were able to get a higher bandwidth for the antenna by first determining its optimal dimensions and then optimizing those dimensions. After that, we adjusted the system by adjusting the quantity of pins, the configuration of the ground, and the volume of the distilled water. In the end, our findings were much improved.

At this time, we have an antenna that operates at 900MHz and has a bandwidth close to 2.3 GHz. Additionally, the gain and conductivity of this antenna have been improved.

An array of antennas has been placed around a cylindrical shape that mimics the Cole-Cole parameters of women breast. The idea of this simulation is to have a better understanding of the behaviour of the antennas array in real practical experiment. The findings show a promising result that can defiantly be taken to the lab experiment and test the antenna with a phantom. Due to that we have made a set of tests to have a phantom that can handle the temperature of out antenna and eventually we might be able to heal some breast tumours without a surgery. The results show as well smooth distribution of the antennas array around the breast.

We want to create a new phantom with completely new materials, which will be based on the findings that we received from performing a wide variety of experiments, particularly those mixes that imitate the dielectric characteristics of breast tissues (Fat, Skin, Tumor, and Gland). This phantom will be ideal for usage in a wide variety of biological therapies, including applications of ablation and hyperthermia, and others. In addition to this, the printing of the new, improved design of the Bow-tie antenna so that it may be tested with our brand-new phantom. The primary objective of all of this study is to develop a completely new system that can be used in any breast hyperthermia therapy.

For comparison purposes, our research has resulted and showed in the development of an antenna that is suitable for use in a wide variety of applications due to its low operating frequency, small size even when operating in a lossy medium, ease of implementation, and broad bandwidth. For more comparison results see section 3.4 in chapter three.

REFERENCES

[1] R. W. Habash, R. Bansal, D. Krewski, and H. T. J. C. R. i. B. E. Alhafid, "Thermal therapy, part 2: hyperthermia techniques," vol. 34, no. 6, 2006.

[2] M. W. Dewhirst, J. Abraham, and B. Viglianti, "Evolution of thermal dosimetry for application of hyperthermia to treat cancer," in Advances in heat transfer, vol. 47: Elsevier, 2015, pp. 397-421.

[3] A. Cheung and J. J. I. P. A. Al-Atrash, "Microwave hyperthermia for cancer therapy," vol. 134, no. 6, pp. 493-522, 1987.

[4] J. A. Kong, Progress in electromagnetics research. Elsevier, 2012.

[5] P. Wust et al., "Hyperthermia in combined treatment of cancer," vol. 3, no. 8, pp. 487-497, 2002.

[6] Y.-X. Du, X.-L. Xi, and W. Guo, "The design and simulation of two-armed spiral antenna for microwave hyperthermia," in 2011 5th International Conference on Bioinformatics and Biomedical Engineering, 2011, pp. 1-4: IEEE.

[7] J. J. P. i. M. Lagendijk and Biology, "Hyperthermia treatment planning," vol. 45, no. 5, p. R61, 2000.

[8] D. Sardari and N. Verga, Cancer treatment with hyperthermia. Citeseer, 2011.

[9] C. f. D. Control and Prevention, "Invasive cancer incidence-United States, 2009," vol. 62, no. 7, pp. 113-118, 2013.

[10] P. T. Nguyen, A. Abbosh, S. J. I. T. o. a. Crozier, and propagation, "Microwave hyperthermia for breast cancer treatment using electromagnetic and thermal focusing tested on realistic breast models and antenna arrays," vol. 63, no. 10, pp. 4426-4434, 2015.

[11] H. A. Elkayal, N. E. Ismail, and M. J. A. E. J. Lotfy, "Microwaves for breast cancer treatments," vol. 54, no. 4, pp. 1105-1113, 2015.

[12] R. Gonçalves Licursi de Mello, A. C. Lepage, X. J. I. M. Begaud, Antennas, and Propagation, "The bow-tie antenna: Performance limitations and improvements," vol. 16, no. 5, pp. 283-294, 2022.

[13] B. Harchandra and R. J. I. Singh, "Analysis and design of bowtie antenna with different shapes and structures," vol. 18, no. 4, pp. 171-175, 2014.

[14] T. W. Eigentler et al., "Wideband self-grounded bow-tie antenna for thermal mr," vol. 33, no. 5, p. e4274, 2020.

[15] P. Takook, M. Persson, J. Gellermann, and H. D. J. I. J. o. H. Trefná, "Compact self-grounded Bow-Tie antenna design for an UWB phased-array hyperthermia applicator," vol. 33, no. 4, pp. 387-400, 2017.

[16] W. J. I. T. o. A. Curtis and Propagation, "Spiral antennas," vol. 8, no. 3, pp. 298-306, 1960.

[17] Y.-X. Du, X.-L. Xi, and L. Qin, "The design of four-arm spiral antenna for microwave hyperthermia," in 2010 4th International Conference on Bioinformatics and Biomedical Engineering, 2010, pp. 1-3: IEEE.

[18] J. Johnson, D. Neuman, P. Maccarini, T. Juang, P. Stauffer, and P. J. I. J. o. H. Turner, "Evaluation of a dual-arm Archimedean spiral array for microwave hyperthermia," vol. 22, no. 6, pp. 475-490, 2006.

[19] Y.-X. Du, L. Qin, and X.-L. Xi, "The analysis and simulation of microstrip spiral antenna for microwave hyperthermia," in 2009 3rd International Conference on Bioinformatics and Biomedical Engineering, 2009, pp. 1-4: IEEE.

[20] E. Korkmaz, O. Isik, M. A. J. I. J. o. A. Nassor, and Propagation, "A compact microstrip spiral antenna embedded in water bolus for hyperthermia applications," vol. 2013, 2013.

[21] M. Aldhaeebi and I. Elshafiey, "New antenna design for hyperthermia treatment of human head," in 2014 UKSim-AMSS 16th International Conference on Computer Modelling and Simulation, 2014, pp. 96-100: IEEE.

[22] M. A. Aldhaeebi, M. A. Alzabidi, I. Elshafiey, and A. F. Sheta, "Development of UWB antenna array for hyperthermia treatment," in 2013 IEEE Symposium on Wireless Technology & Applications (ISWTA), 2013, pp. 355-358: IEEE.

[23] M. Aldhaeebi, M. Alzabidi, I. Elshafiey, and Z. Siddiqui, "Antipodal Vivaldi antenna for hyperthermia treatment," in 2013 Loughborough Antennas & Propagation Conference (LAPC), 2013, pp. 37-42: IEEE.

[24] K. Uday, G. J. J. o. A. S. Rajamurugan, and Technology, "Influence of process parameters and its effects on friction stir welding of dissimilar aluminium alloy and its composites–a review," pp. 1-34, 2022.

[25] P. Nguyen, A. Abbosh, S. J. I. A. Crozier, and W. P. Letters, "Thermo-dielectric breast phantom for experimental studies of microwave hyperthermia," vol. 15, pp. 476-479, 2015.

[26] A. Sayinti, B. Türetken, E. Açikalin, K. Çoban, and H. Eroğlu, "Custom gland and skin tissue phantom fabrication for use in breast cancer detection research studies," in 2014 XXXIth URSI General Assembly and Scientific Symposium (URSI GASS), 2014, pp. 1-4: IEEE.

[27] S. Di Meo, L. Pasotti, M. Pasian, and G. Matrone, "Realization of breast tissue-mimicking phantom materials: dielectric characterization in the 0.5-50 GHz frequency range," in 2018 IEEE International Microwave Biomedical Conference (IMBioC), 2018, pp. 37-39: IEEE.

[28] R. Clemens and T. Graham, Introduction to manuscript studies. Cornell University Press Ithaca, 2007.

[29] A. Sayinti, E. Açikalin, K. Çoban, and A. J. A. P. P. A. Vertii, "Complex Dielectric Coefficient of Breast Phantom Prepared for Breast Cancer Detection," vol. 123, no. 2, pp. 464-466, 2013.

[30] Y. He et al., "3D-printed breast phantom for multi-purpose and multi-modality imaging," vol. 9, no. 1, p. 63, 2019.

[31] L. S. Solanki, S. Singh, and D. J. O. Singh, "Development and modelling of the dielectric properties of tissue-mimicking phantom materials for ultra-wideband microwave breast cancer detection," vol. 127, no. 4, pp. 2217-2225, 2016.

[32] N. Joachimowicz, B. Duchêne, C. Conessa, and O. J. D. Meyer, "Anthropomorphic breast and head phantoms for microwave imaging," vol. 8, no. 4, p. 85, 2018.

[33] M. Lazebnik, M. C. Converse, J. H. Booske, S. C. J. P. i. M. Hagness, and Biology, "Ultrawideband temperature-dependent dielectric properties of animal liver tissue in the microwave frequency range," vol. 51, no. 7, p. 1941, 2006.

[34] N. Arteaga-Marrero, E. Villa, J. González-Fernández, Y. Martín, and J. J. P. o. Ruiz-Alzola, "Polyvinyl alcohol cryogel phantoms of biological tissues for wideband operation at microwave frequencies," vol. 14, no. 7, p. e0219997, 2019.

[35] R. Ortega-Palacios, L. Leija, A. Vera, and M. Cepeda, "Measurement of breast-tumor phantom dielectric properties for microwave breast cancer treatment evaluation," in 2010 7th International conference on electrical engineering computing science and automatic control, 2010, pp. 216-219: IEEE.

[36] A. Partanen et al., "Mild hyperthermia with magnetic resonance-guided high-intensity focused ultrasound for applications in drug delivery," vol. 28, no. 4, pp. 320-336, 2012.

[37] A. Dabbagh, B. J. J. Abdullah, N. H. Abu Kasim, and C. J. I. j. o. h. Ramasindarum, "Reusable heat-sensitive phantom for precise estimation of thermal profile in hyperthermia application," vol. 30, no. 1, pp. 66-74, 2014.

[38] K. Tomura et al., "The usefulness of mobile insulator sheets for the optimisation of deep heating area for regional hyperthermia using a capacitively coupled heating method: phantom, simulation and clinical prospective studies," vol. 34, no. 7, pp. 1092-1103, 2018.

[39] E. M. Cheng, M. F. B. Abd Malek, M. Ahmed, K. Y. You, K. Y. Lee, and H. J. P. I. E. R. Nornikman, "The use of dielectric mixture equations to analyze the dielectric properties of a mixture of rubber tire dust and rice husks in a microwave absorber," vol. 129, pp. 559-578, 2012.

[40] D. M. Hagl, D. Popovic, S. C. Hagness, J. H. Booske, M. J. I. T. o. M. T. Okoniewski, and Techniques, "Sensing volume of open-ended coaxial probes for dielectric characterization of breast tissue at microwave frequencies," vol. 51, no. 4, pp. 1194-1206, 2003.

[41] E. Porter, M. J. I. T. o. A. O'Halloran, and Propagation, "Investigation of histology region in dielectric measurements of heterogeneous tissues," vol. 65, no. 10, pp. 5541-5552, 2017.

[42] D. Misra, M. Chabbra, B. R. Epstein, M. Microtznik, K. R. J. I. t. o. m. t. Foster, and techniques, "Noninvasive electrical characterization of materials at microwave

frequencies using an open-ended coaxial line: Test of an improved calibration technique," vol. 38, no. 1, pp. 8-14, 1990.

[43] C. Gabriel, A. J. P. i. M. Peyman, and Biology, "Dielectric measurement: error analysis and assessment of uncertainty," vol. 51, no. 23, p. 6033, 2006.

[44] J. van der Zee, D. González, G. C. van Rhoon, J. D. van Dijk, W. L. van Putten, and A. A. J. T. L. Hart, "Comparison of radiotherapy alone with radiotherapy plus hyperthermia in locally advanced pelvic tumours: a prospective, randomised, multicentre trial," vol. 355, no. 9210, pp. 1119-1125, 2000.

[45] R. D. Issels et al., "Neo-adjuvant chemotherapy alone or with regional hyperthermia for localised high-risk soft-tissue sarcoma: a randomised phase 3 multicentre study," vol. 11, no. 6, pp. 561-570, 2010.

[46] P. F. J. I. T. o. B. E. Turner, "Regional hyperthermia with an annular phased array," no. 1, pp. 106-114, 1984.

[47] H. Kroeze, J. Van de Kamer, A. De Leeuw, J. J. P. i. M. Lagendijk, and Biology, "Regional hyperthermia applicator design using FDTD modelling," vol. 46, no. 7, p. 1919, 2001.

[48] M. Paulides et al., "The HYPERcollar: a novel applicator for hyperthermia in the head and neck," vol. 23, no. 7, pp. 567-576, 2007.

[49] P. Togni et al., "Electromagnetic redesign of the HYPERcollar applicator: toward improved deep local head-and-neck hyperthermia," vol. 58, no. 17, p. 5997, 2013.

[50] M. M. Paulides, J. F. Bakker, N. Chavannes, and G. C. J. I. T. o. B. E. Van Rhoon, "A patch antenna design for application in a phased-array head and neck hyperthermia applicator," vol. 54, no. 11, pp. 2057-2063, 2007.

[51] P. R. J. I. J. o. H. Stauffer, "Evolving technology for thermal therapy of cancer," vol. 21, no. 8, pp. 731-744, 2005.

[52] O. Isik, E. Korkmaz, S. Kara, M. A. Nassor, and B. Turetken, "Development of a hyperthermia applicator with compact microstrip antennas," in Proceedings of the 2012 IEEE International Symposium on Antennas and Propagation, 2012, pp. 1-2: IEEE.

[53] Ö. Işik, E. Korkmaz, and B. Türetken, "Antenna arrangement considerations for microwave hyperthermia applications," in 2011 XXXth URSI General Assembly and Scientific Symposium, 2011, pp. 1-3: IEEE.

[54] M. Asili et al., "Flexible microwave antenna applicator for chemo-thermotherapy of the breast," vol. 14, pp. 1778-1781, 2015.