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Design and Analysis of Terahertz Antenna for Breast Tumor Detection

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ABSTRACT:

In this paper, two different types of rectangular patch antennas are designed for broadband gigahertz and terahertz applications. First, a patch antenna is modeled using PEC for gigahertz applications. Secondly, a patch antenna is modeled using graphene for terahertz applications. Without exposing the patient to ionizing radiations, malignant lesions can be detected by using the dielectric discontinuities in the tissues. The simulation results show a degraded reflection coefficient due to the use of PEC and graphene. Therefore, the reflection coefficient is above -10 dB at 33 GHz and at 2.6 THz and also VSWR is less than 2 dB in both gigahertz and terahertz. The purpose of this work is to develop a simple, low-cost miniaturized mmWave imaging antennasensor that can be used to detection of breast tumors or cancers in women by monitoring the changes in the antenna's S11 parameter.

The time-domain solver of CST MWS software is used to evaluate the performance of the patch antennas in both gigahertz and terahertz frequency. In gigahertz we can absorb deflection in the resonant frequency within 1 GHz bandwidth and in terahertz we can absorb deflection in the resonant frequency about 0.005THz bandwidth.

The antenna is capable of detecting tiny malignant tumors that size ≥1 mm inside the breast fantom. Other factors like S21,E-Field and farfield are also simulated to measure the efficiency of the antennas designed in both gigahertz and terahertz frequencies. By these results we conclude theantenna can detect tumor presence

Keywords: Breast Cancer, Tumor Detection, Terahertz Antenna

2. INTRODUCTION

Breast cancer, a widespread and potentially life-threatening disease, demands innovative approaches for early detection and improved treatment outcomes. Terahertz (THz) technology has emerged as a promising frontier in the realm of medical diagnostics, offering a unique window into the electromagnetic spectrum that holds the potential to revolutionize the field of breast tumor detection. Terahertz waves occupy the spectrum between microwave and infrared radiation, typically ranging from 0.1 to 10 terahertz. What makes this region particularly intriguing is its ability to penetrate biological tissues with remarkable precision. In the context of breast tumor detection, harnessing the power of terahertz waves introduces a new dimension to non-invasive, early diagnosis.

Traditional imaging techniques, such as X-rays and ultrasounds, have limitations when it comes to differentiating between healthy and abnormal tissues, especially in the early stages of tumor development. Terahertz technology, with its non-ionizing nature and unique interaction with water molecules, provides a novel solution to address these challenges. Here we focus on the integration of terahertz antennas in the intricate landscape of breast tumor detection. Antennas, specifically designed to operate in the terahertz frequency range, become indispensable tools in this endeavour. These antennas act as receptors, capturing the subtle electromagnetic signals emitted by tissues and enabling the identification of abnormalities at an early stage. We will also delve into the fundamental principles of terahertz waves, unravel the intricacies of designing antennas for this unique frequency range, and examine how these technologies synergize to create a powerful tool for early diagnosis.

3. MICROSTRIP PATCH ANTENNAS

Microstrip patch antennas represent a compact and versatile category of antennas that have gained prominence in various wireless communication and sensing applications. These antennas, characterized by their small size and planar structure, offer advantages such as ease of integration into electronic devices, portability, and flexibility in design. Microstrip patch antennas operate across a range of frequencies, including microwave frequencies, making them suitable for diverse applications. Their simplicity in design, often consisting of a metal patch on a dielectric substrate, contributes to their cost-effectiveness and ease of manufacturing. Despite their miniature size, microstrip patch antennas exhibit significant performance capabilities, making them valuable components in modern communication systems, satellite technology. The unique attributes of microstrip patch antennas continue to drive research and innovation in antenna technology, paving the way for their continued integration into various cutting- edge technologies.

INTRODUCTION TO TERAHERTZ TECHNOLOGY

Terahertz (THz) antennas have shown promise in the field of medical imaging, including breast tumor detection. THz waves, which lie in the electromagnetic spectrum between microwave and infrared radiation, have the ability to penetrate biological tissues, providing detailed information without the ionizing radiation associated with X-rays. THz antennas are crucial components in emitting and sreceiving these waves for imaging purposes.

In the context of breast tumor detection, THz imaging can offer advantages such as high resolution and the ability to differentiate between healthy and diseased tissues based on theirunique spectral signatures. THz waves can reveal molecular information related to tissue composition, helping in the early identification of abnormalities associated with breast tumors. The non-invasive nature of THz imaging is particularly valuable for breast cancer screening. THz antennas contribute to the development of imaging systems that can be used for early detection, enabling clinicians to identify potential issues before they become symptomatic.

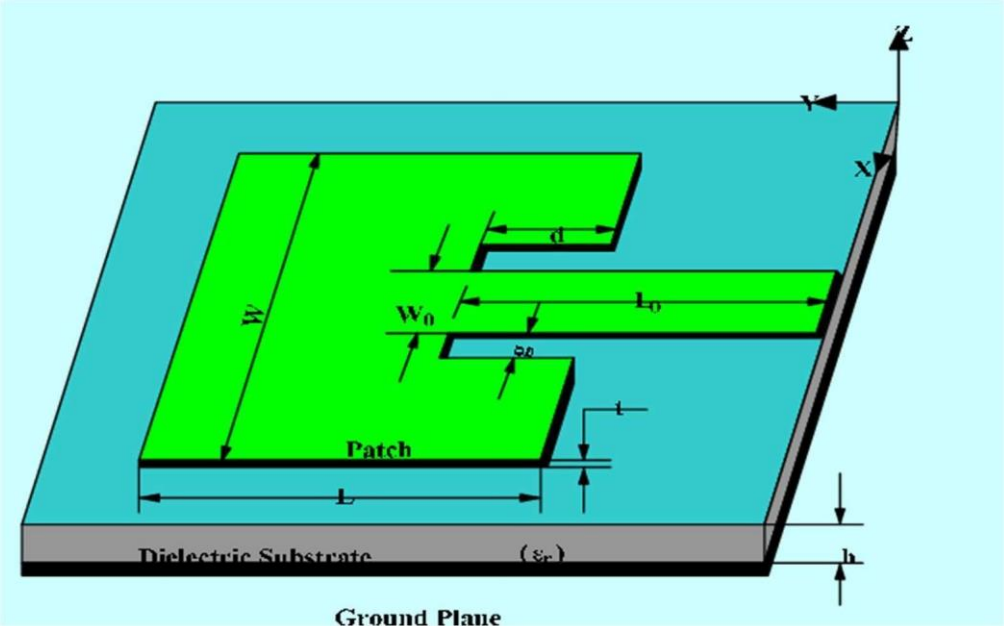


Figure 3.1 Microstrip patch Antenna with inset feed

Tumor detection for Terahertz frequency

A terahertz (THz) graphene-based patch antenna operating at 2.6 THz for tumor detection involves the interaction of electromagnetic waves in the terahertz frequency range with biological tissues. The unique properties of graphene, such as its high conductivity andflexibility, play a crucial role in the functionality of the antenna.

The patch of the antenna is composed of graphene, a single layer of carbon atoms arranged in a hexagonal lattice. Graphene's high electrical conductivity allows it to efficiently transmit and receive terahertz signals. The graphene layer is typically integrated onto a dielectric substrate. The dielectric substrate supports the graphene patch and influences the antenna's mechanical properties. The choice of substrate is crucial for flexibility, biocompatibility, and overall antenna performance. The antenna is designed to operate at 2.6 THz, which falls within the terahertz frequency range. When an electrical signal is applied to the graphene patch, it interacts with the graphene material, generating terahertz electromagnetic waves.

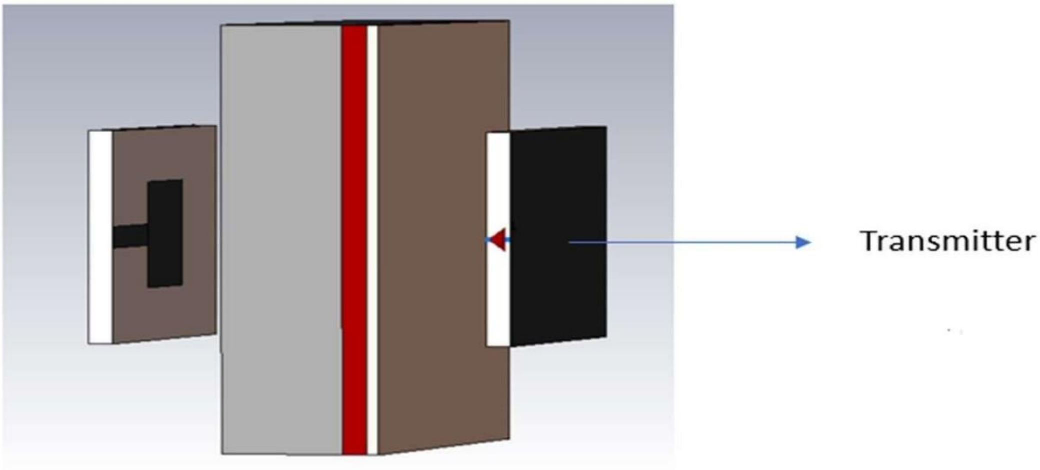


Figure 3.2 Transmitting Antenna for Terahertz Frequency

The emitted terahertz waves penetrate biological tissues, including breast tissues in the case of tumor detection. Terahertz waves have the unique ability to provide detailed information about the molecular composition of tissues, making them suitable for medical imaging applications. As the terahertz waves interact with the tissues, variations in the electromagnetic properties occur. Tumors and abnormal tissue structures may exhibit different dielectric properties compared to healthy tissues. These variations can be detected by the graphene-based patch antenna. The graphene patch antenna acts as a sensor, capturing the reflected or transmitted terahertz signals after interaction with tissues. Changes in the signal characteristics, such as amplitude, phase, or frequency, can indicate the presence of tumors. The received signals are processed and analyzed to create an image or map of the scanned area. Signal processing techniques help distinguish between healthy and abnormal tissues, enabling the identification and localization of tumors. Graphene's flexibility allowsthe antenna to conform to the shape of the body, facilitating better contact with irregular surfaces. This adaptability enhances the antenna's effectiveness in real-world medical imaging scenarios.

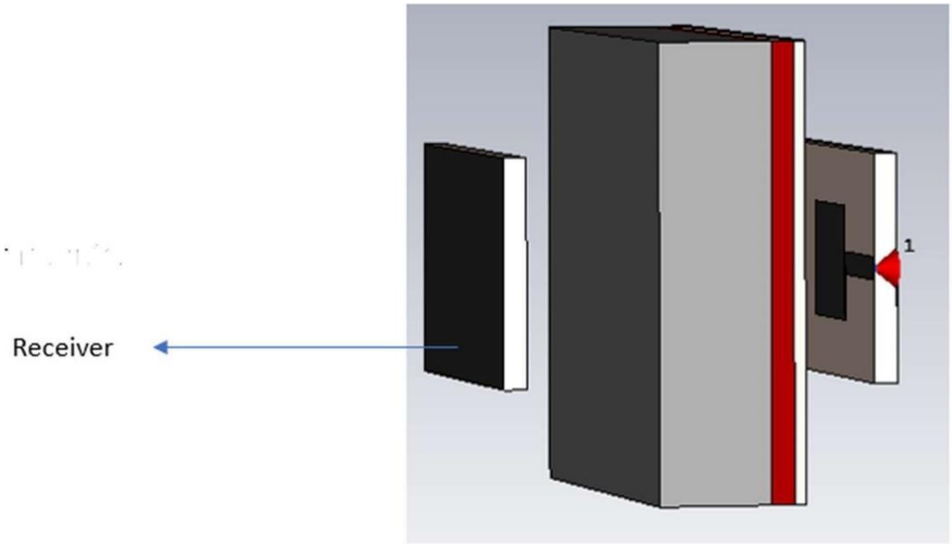


Figure 3.3 Receiving Antenna for Terahertz Frequency

A graphene-based patch antenna that can work as a biosensor for breast tumor detection in the terahertz band (0.1-6 THz).. The antenna is placed near the breast tissue cells (normal and tumor) and the resonance frequency shift is measured as an indicator of the tumor presence. The antenna has a high sensitivity of 8 THz/RIU and a low specific absorption rate (SAR) of 0.07 W at 4.25 THz, which means it is safe and effective for biomedical applications. This can enhance the detection accuracy and flexibility of the sensor.

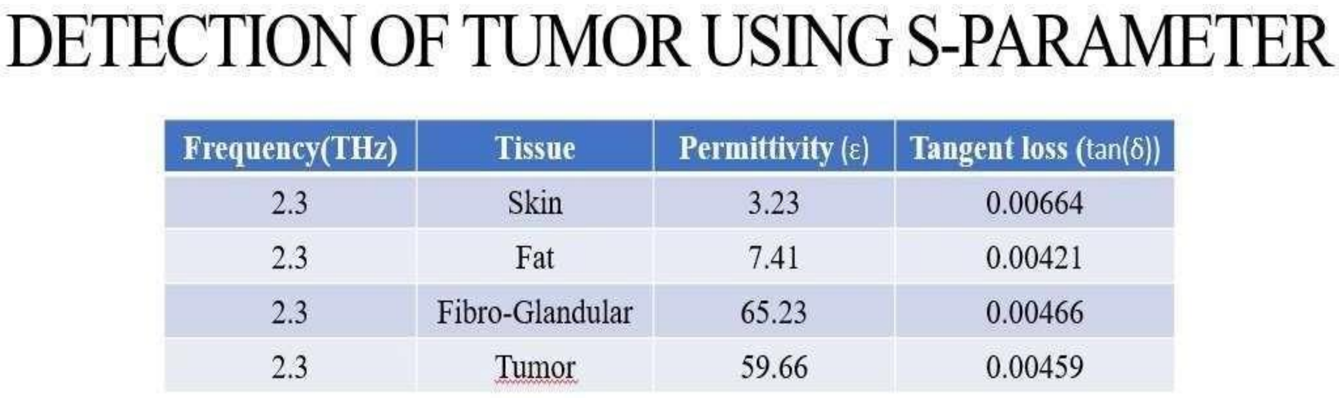
A graphene-based patch antenna operating at 2.6 THz for tumor detection utilizes the unique properties of graphene to generate and interact with terahertz waves, allowing for the sensitive detection of abnormalities in biological tissues, including breast tumors. While challenges in fabrication techniques and optimization of sensitivity persist, ongoing research endeavors aim to address these obstacles. The potential for real-time, high-resolution imaging using graphene-based terahertz antennas introduces exciting possibilities for early cancer detection and personalized medicine. The tumor detection mechanism, driven by the interaction between terahertz waves and tissues, provides a novel approach for non-invasive imaging. Graphene's flexibility ensures that the antenna can conform to the complex contours of the body, optimizing its contact with irregular surfaces and enhancing its effectiveness in real-world medical scenarios. The integration of graphene into patch antennas operating at terahertz frequencies represents a cutting-edge avenue with transformative implications for medical imaging, offering a potent tool for enhancing diagnostic precision and ultimately improving patient outcomes, particularly in the realm of breast tumor detection.

Parameters	**Value (μm)**
Substrate length (Ls)	30
Substrate height (Hs)	2
Substrate width (Ws)	20
Patch length (Lp)	10
Patch width (Wp)	10
Microstrip thickness (Mt)	0.01
Feed width (Mw)	2
Feed length (ML)	10
Graphene thickness	0.01
Graphene relaxtime	1
Graph chempotential	1.6
Graphne temperature	293

Table 3.2 Antenna Parameters for Terahertz frequency of 2.6Thz

These values collectively define the geometry and dimensions of the microstrip patch antenna, which is optimized for operation at 2.6 THz. The specific dimensions are carefully chosen to achieve resonance at the desired frequency and to facilitate efficient radiation and reception of electromagnetic waves for tumor detection applications.

4. SYSTEM DESIGN AT THz



DETECTION OF TUMOR USING S-PARAMETER

Frequency(THz)	Tissue	Permittivity (ε)	Tangent loss (tan(δ))
2.3	Skin	3.23	0.00664
2.3	Fat	7.41	0.00421
2.3	Fibro-Glandular	65.23	0.00466
2.3	Tumor	59.66	0.00459

Table 4.1 Parameters of a human breast

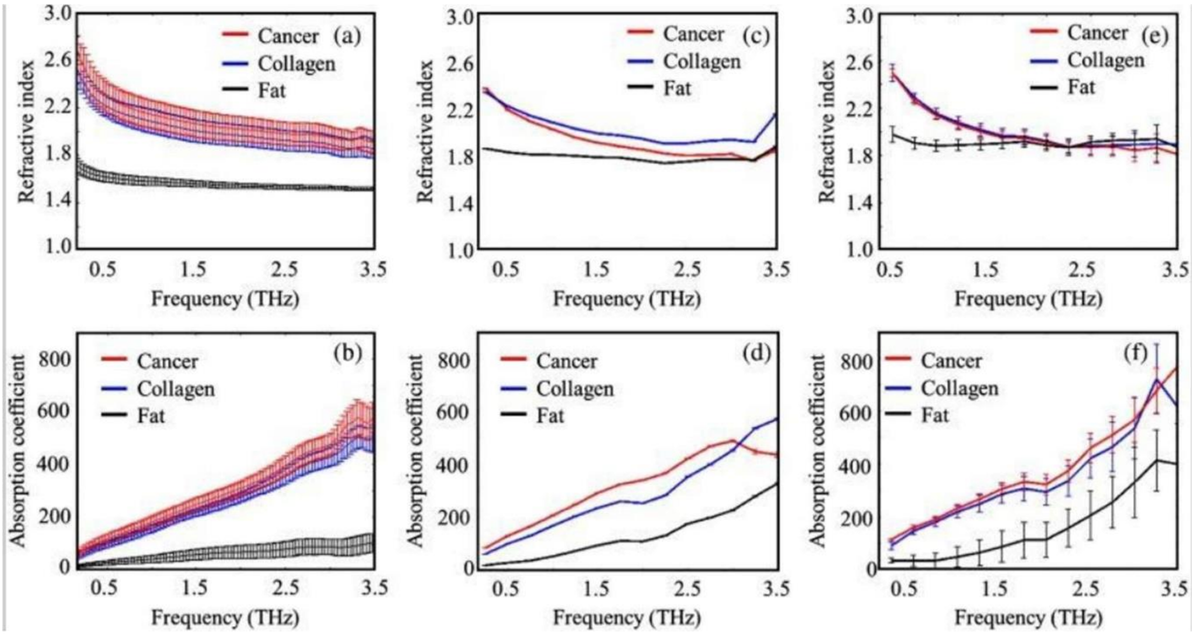
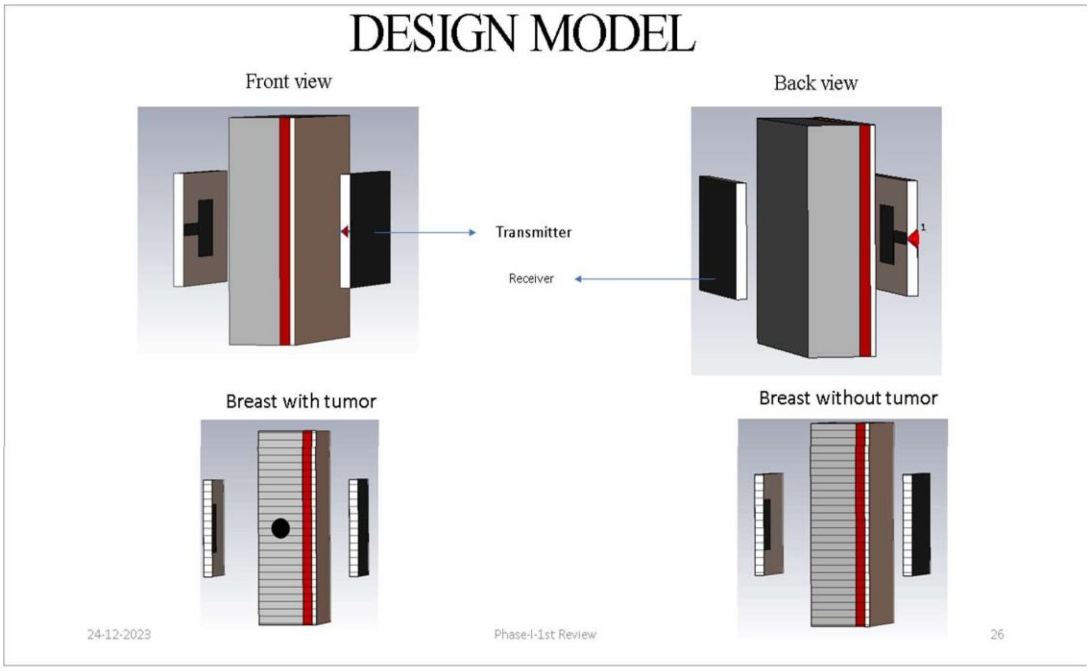


Figure 4.2 Graph for breast parameters



DESIGN MODEL

Front view

Back view

Transmitter

Receiver

Breast with tumor

Breast without tumor

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Figure 4.3 System design at different angles at THz

The above proposed model is the exact same model like system design for GHz.The above setup is operated at Terahertz frequency

RESULTS

POST SIMULATION AT THz SETUP

The following results were obtained after simulating our breast fantom in CST environment

S-PARAMETER ANALYSIS AT THz

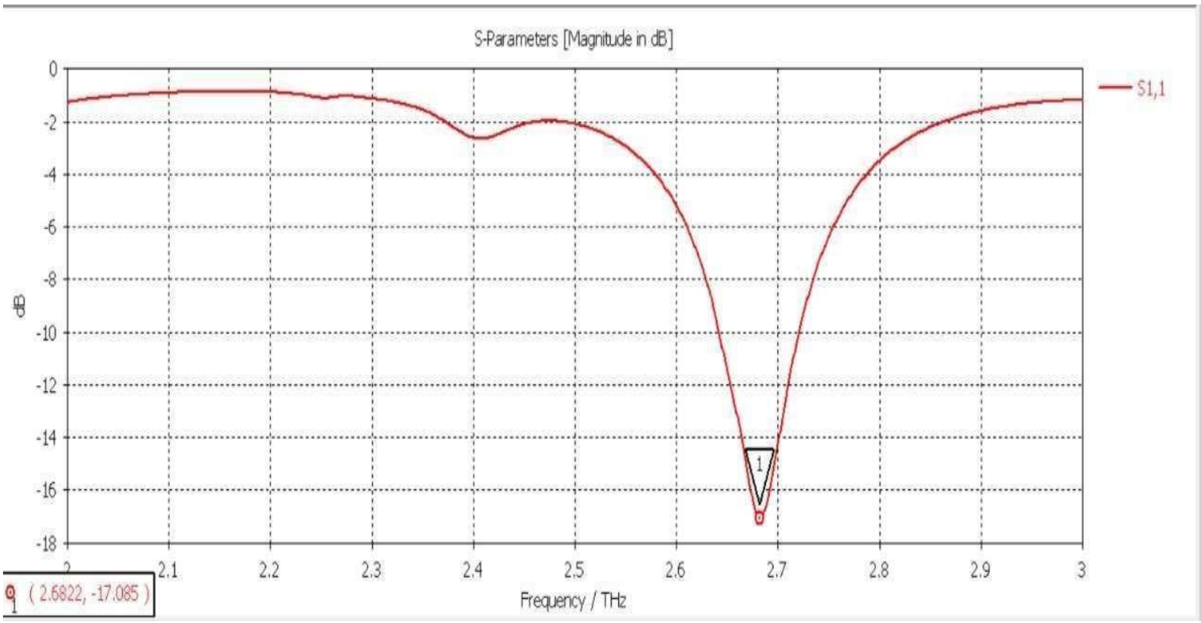

Figure 5.1 S11 ANALYSIS FOR SETUP WITHOUT TUMOR

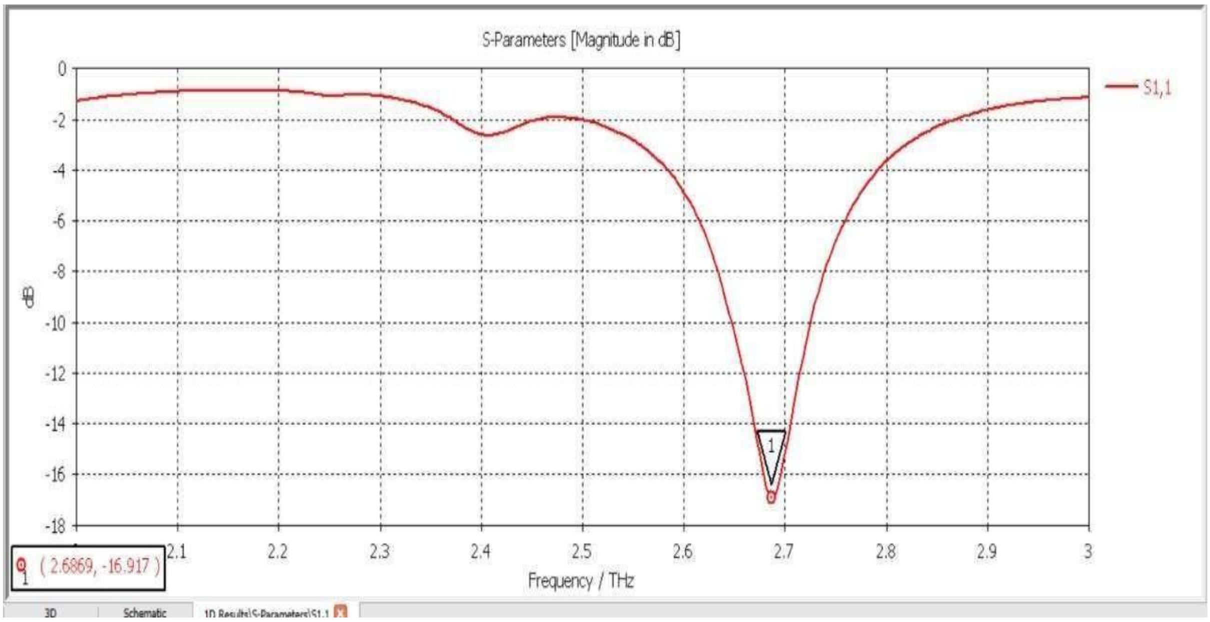

Figure 5.2 S11 ANALYSIS FOR SETUP WITH TUMOR

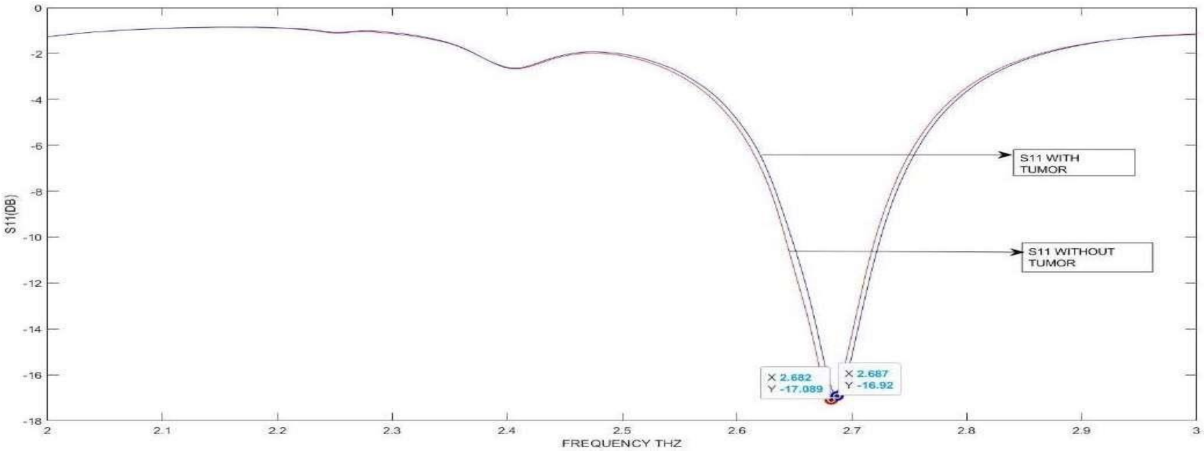

Figure 5.3 COMPARISON OF S11 PARAMETER WITHOUT AND WITH TUMOR

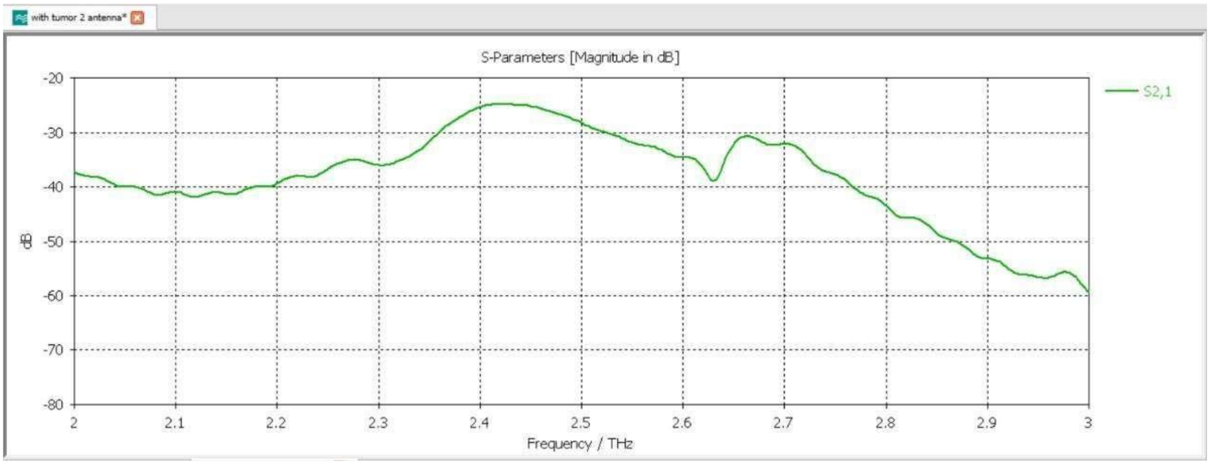

Figure 5.4 S21 ANALYSIS FOR SETUP WITHOUT TUMOR

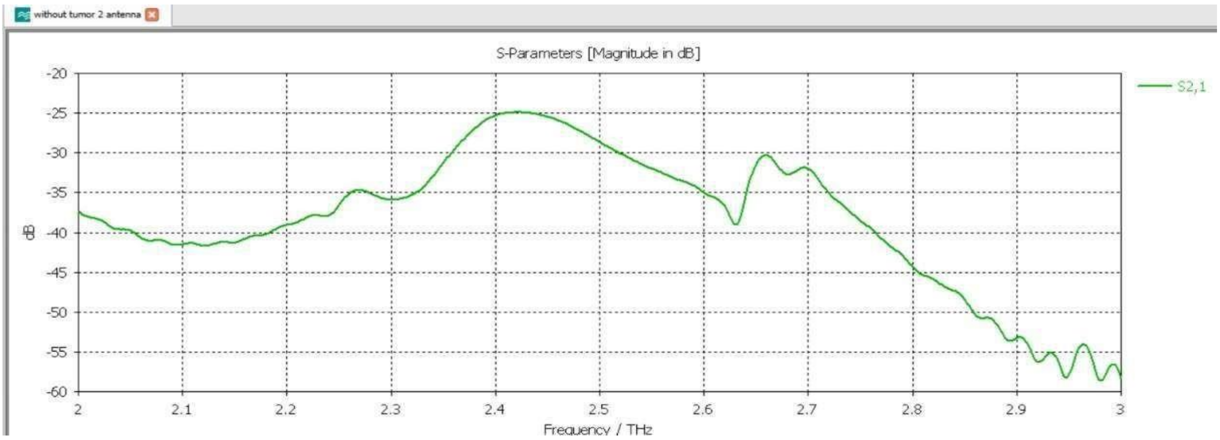

Figure 5.5 S21 ANALYSIS FOR SETUP WITH TUMOR

In the intricate realm of electromagnetic simulations, specifically in the context of microstrip patch antennas simulated in CST Studio Suite within a breast setup, the parameters S11 and S21 take center stage. These parameters play a pivotal role in elucidating the resonance behavior and transmission characteristics of the antenna, offering profound insights into its performance and suitability for various applications.

S11 Parameter: Reflection Coefficient

S11, the reflection coefficient, is a crucial metric that quantifies the amount of power reflected back from the antenna to the source. In the specified frequency range of 2.682 THz(Figure 5.1) to 2.687 THz(Figure 5.2), the analysis of S11 provides valuable information about the impedance matching between the microstrip patch antenna and the surrounding medium, which, in this case, is the breast tissue. Optimal impedance matching is a cornerstone for efficient power transfer and radiation. At the resonant frequency, S11 is minimized, indicating that the antenna is effectively tuned to the operating frequency. This minimization signifies that a minimal amount of energy is being reflected back, and instead, a significant portion is transmitted into the surrounding medium.

In the context of a breast setup, where biomedical applications such as medical imaging and sensing are contemplated, achieving low S11 values at the resonant frequency is of paramount importance. The reason lies in the need to minimize reflections within the tissue, ensuring that more energy is absorbed for various applications. For instance, in medical imaging, where clarity and precision are imperative, minimizing reflections enhances the efficiency of signal penetration through the breast tissue, contributing to more accurate diagnostic information.

S21 Parameter: Transmission Coefficient:

S21, the transmission coefficient, is equally critical, shedding light on the amount of power transmitted through the antenna. Within a breast setup, maintaining an S21 in both (Figure 5.4 and Figure 5.5) value less than -30 dB is often considered a significant criterion. This low S21 value indicates minimal power loss during transmission, signifying that a substantial portion of the electromagnetic energy is efficiently penetrating the biological tissue. The magnitude of S21 reflects the efficiency of the antenna in transmitting signals through the 40 complex and varied structure of breast tissue.The significance of achieving a low S21 value is multifaceted. In biomedical applications, where microstrip patch antennas may find application in medical imaging or sensing, the quality of signal transmission through the tissue is paramount. A low S21 implies that the antenna is effective in penetrating the tissuewith minimal energy loss, ensuring that the transmitted signal remains robust and discernible. This characteristic is particularly crucial in scenarios such as early disease detection or monitoring, where the reliability of the signal through biological tissues is fundamental for the accuracy of diagnostic or sensing information.

Interplay of S11 and S21 in Frequency Analysis:

The resonance behavior of the microstrip patch antenna is intricately tied to the interplay between S11 and S21 across the specified frequency range. Identifying the resonant frequency involves scrutinizing the S11 parameter. At the resonant frequency, S11 is minimized, signifying that the antenna is optimally tuned to the operating frequency, and impedance matching is at its best. This is a critical point, as it marks the frequency at which the antenna exhibits maximum efficiency in absorbing and transmitting electromagnetic energy.

Simultaneously, the analysis of S21 across the frequency range is imperative for understanding how well the antenna transmits signals through the breast tissue. The criterion of maintaining an S21 value less than -30 dB(Figure 5.4 and Figure 5.5) underscores the need for efficient signal transmission with minimal loss. Achieving this low S21 value ensures that the microstrip patch antenna can effectively navigate the complexities of the biological medium, making it a reliable candidate for applications where signal integrity through tissues is paramount.

VSWR AND E-FIELD PATTERN

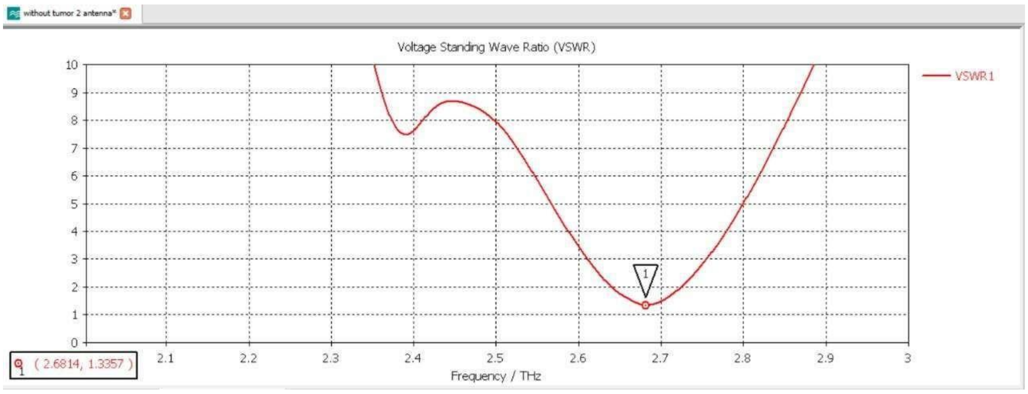

Figure 5.6 VSWR RESULT FOR SETUP WITHOUT TUMOR

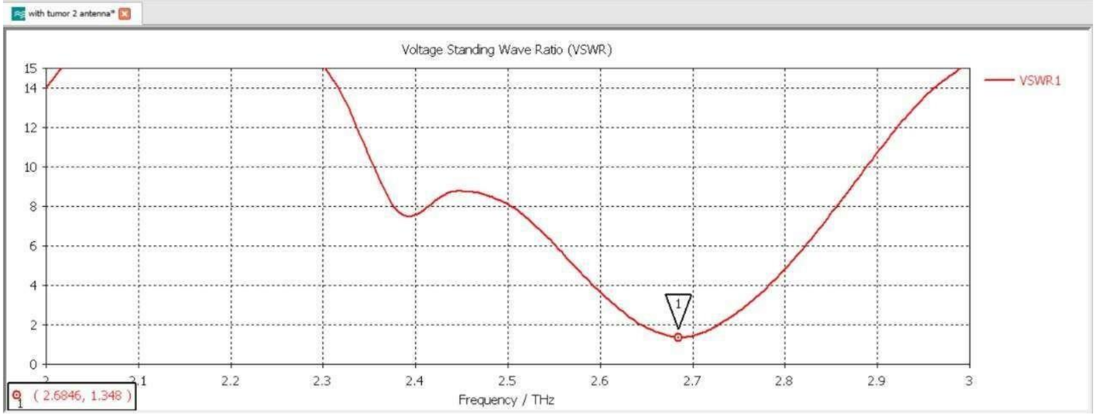

Figure 5.7 VSWR RESULT FOR SETUP WITH TUMOR

From both the above Figure 5.6 and Figure 5.7 we can acknowledge VSWR is 1.3. A Voltage Standing Wave Ratio (VSWR) of 1.3 is indicative of an exceptionally well-matched antenna system. VSWR is a measure of how efficiently power is transferred from a source, such as a transmitter, to the load, which is the antenna, and how much is reflected back. A VSWR of 1.3 signifies minimal signal reflection, meaning that the antenna is almost perfectly impedance-matched to the transmission line and source. In practical terms, this implies that a vast majority of the power from the source is effectively reaching the antenna, minimizing signal loss due to reflections. An ideal VSWR value is 1, indicating perfect matching, and as the value increases, signal loss and inefficiency also rise. Therefore, a VSWR of 1.3 underscores the excellent performance and optimal matching of the antenna system, ensuring efficient power transfer and radiation.

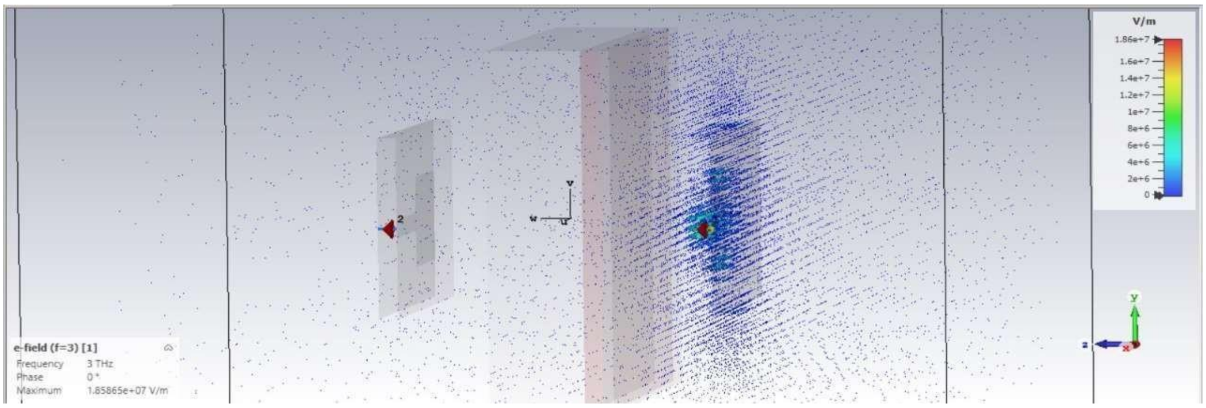

Figure 5.8 E-FIELD PATTERN FOR SETUP WITHOUT TUMOR

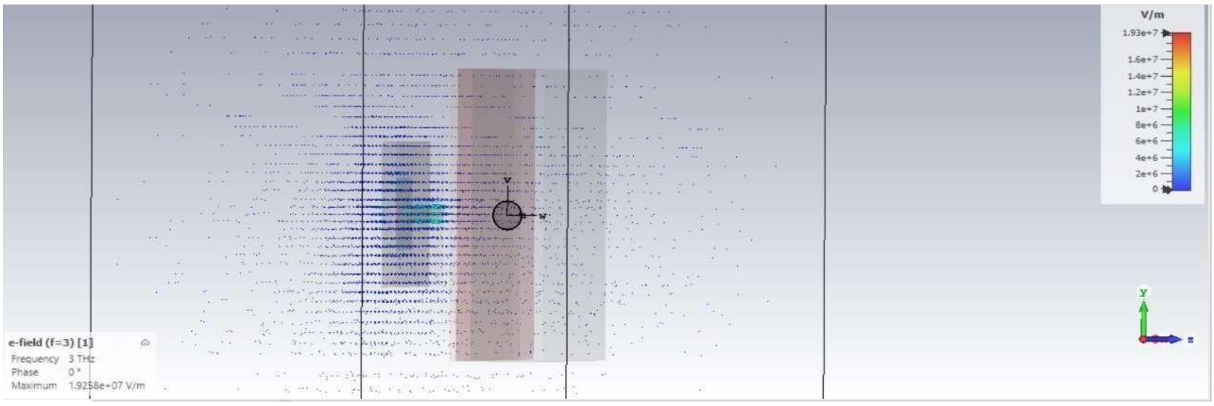

Figure 5.9 E-FIELD PATTERN FOR SETUP WITH TUMOR

The electric field distribution is measured to support the fluctuation of the power distribution in heterogeneous body tissues. It is obvious that the power absorbed by the tissue layers is not uniform, and some of the absorbed power is taken up by the tumor, which causes deflections in the radiation patterns coming from various ray directions.

CONCLUSION FOR RESULTS

In essence, the analysis of S11 and S21 parameters in the simulation of microstrip patch antennas within a breast setup in CST Studio Suite is not merely an exercise in numerical values; it is a profound exploration into the antenna's ability to interact with biological tissues. S11 guides the optimization of resonance characteristics, indicating the frequency atwhich the antenna is most efficient in absorbing and radiating energy. Simultaneously, S21 ensures that the antenna is adept at transmitting signals through the intricate and variable structure of breast tissue with minimal loss.

CONCLUSION

The integration of terahertz (THz) technology and graphene-based patch antennas for breast tumor detection represents a groundbreaking approach in the field of medical diagnostics. By harnessing the unique properties of graphene, such as high conductivity and flexibility, we have endeavored to create antennas that operate within the terahertz frequency range, specifically at 2.6 THz, for enhanced sensitivity and precision in imaging applications.In this innovative design, the graphene-based patch antenna serves as a crucial component, efficiently generating and interacting with terahertz electromagnetic waves. The dielectric substrate, supporting the graphene layer, contributes to the antenna's mechanical properties, offering flexibility and adaptability to irregular surfaces. This adaptability is particularly significant for conformal imaging, allowing the antenna to closely adhere to the complex contours of the human body, especially in breast cancer detection scenarios.The graphene-based patch antenna acts as a sensor, capturing and processing the reflected or transmitted terahertz signals. Signal analysis, including parameters like amplitude, phase, and frequency, facilitates the creation of detailed images or maps of the scanned area. This real-time imaging capability opens new avenues for early cancer detection, offering potentialbreakthroughs in medicine

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