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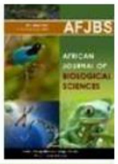

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Precision Tumor Detection in Breast Cancer through Cutting-Edge Millimeter-Wave Antennas

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Abstract.

Breast cancer is one of the most prevalent cancers affecting women worldwide, with early detection significantly improving treatment outcomes and enhancing survival rates. This work aims to develop a simple, low-cost miniaturized mmWave imaging antenna for detecting breast tumors by monitoring changes in the antenna's S11 parameter. The article explores the design of millimeter-wave antennas operating at a central frequency of 33 GHz, constructed on an RT/duroid 5880LZ substrate with a dielectric constant of 2.2, using the HFSS EM simulator. The proposed rectangular mmWave antenna has dimensions of 2.45 mm × 2.5 mm × 0.5 mm, offering substantial penetration capabilities. The simulation examines various scenarios, including breasts without tumors, breasts with tumors, and tumors in different positions. To establish a clearer connection between the alteration of S parameters and tumorous tissues, an S vector was generated. The results from the S11 parameter revealed the capability to detect the presence of tumors and their locations. The designed antenna resonated at 33 GHz with a return loss value of -19.33 dB, a satisfactory bandwidth of 2.10 GHz, a total peak gain of 7.07 dB, and a voltage standing wave ratio of 1.2. These results indicate that the proposed antenna is suitable for tumor detection and localization in breast cancer, as well as for fifth-generation (5G) wireless communication applications.

Keywords: mmWave-Antenna, Breast-Tumor, S-Parameters, BW, Gain, VSWR, 5G.

I. INTRODUCTION

The millimeter wave (mmWave) frequency band has gained increasing popularity in imaging technology due to its ability to penetrate adverse weather conditions and various materials such as clothing, polymers, and human tissue. This frequency band, ranging from 30 GHz to 300 GHz with wavelengths between 10 mm and 1 mm, is used for detecting hidden objects like weapons and explosives, as well as cancer cells. mmWave imaging shows great promise for identifying tumors in the brain and breast. Breast cancer, which can also affect men, is among the most common cancers in women and results from the uncontrolled growth of cells in breast tissue. Research indicates that approximately one in eight women will develop breast cancer in their lifetime, making it a leading cause of cancer-related deaths worldwide, accounting for 6.6% of all cancer deaths[1-2].

Breast examination employs several imaging techniques, including X-ray mammography, ultrasound, MRI, and positron emission tomography (PET). Additionally, microwave imaging is a diagnostic method with unique benefits. For instance, X-ray mammography can be uncomfortable due to ionizing radiation and may occasionally yield inaccurate results. PET scans tend to have lower resolution, while MRI is known for its high cost. On the other hand, radio frequency detection is a safe and cost-effective alternative that can function independently of a physician's direct involvement. Microwave imaging is especially advantageous because it is less expensive and does not involve ionizing radiation [3].

Microwave Imaging (MWI) is an innovative medical diagnostic tool that has received significant attention for its use in detecting breast tumors, brain tumors, early-stage heart failure, and for health monitoring. In MWI, microwaves are sent through the human body with a transmitting antenna that also serves as a receiver. This antenna gathers data by differentiating between microwave signals scattered by various tissues within the body. The collected radiated and scattered energy is then processed for precise diagnosis and analysis.

This research proposes a mmWave antenna sensor that shows great promise for diagnosing early-stage tumors and detecting very small malignant masses. Initial experiments indicate that operating frequencies above 30 GHz can detect tumors as small as 1 mm in breast phantoms. Additionally, this antenna system, operating in this high-frequency range, can enhance gain and efficiency, making it suitable for 5G and future high-speed communication systems [4].For 5G communication infrastructure, there is a growing need for smaller, faster, and higher bandwidth antenna technologies. Single-element microstrip mmWave antennas are particularly promising candidates [5] [6]. The proposed system operates at a central frequency of 33 GHz, with a wide bandwidth of 2.10 GHz aimed at improving the resolution of mmWave images. An important advantage of this antenna sensor is its capability to detect very small tumor cells (≥1 mm, i.e., stage-1) in breast phantoms. The paper starts by discussing breast cancer detection using four microstrip patch antennas to achieve high resolution, focusing on emerging tumor detection designs. The study involved four patch antennas operating at 33 GHz, positioned at the sides of a container. The methodology centered on tracking changes in S-parameters to assess tumor tissue formation and determine its location. Subsequent sections detail the characterization of breast tissue models, followed by the antenna design process. Simulation scenarios, results, and evaluations are presented before the conclusion.

II. DESIGN OF BREAST MODEL

Breast cancer begins with irregular growth within the complex tissue of the breast, encompassing fat, fibrous tissue, glandular tissue, skin, and the areola. This cancerous growth often starts by invading the breast glands or ducts. When there is an abnormal proliferation of fibrous and glandular tissue or a decrease in fatty tissue, it can lead to the formation of dense breast tissue, which serves as an early sign of cancer development [7].

The dielectric properties of breast tissue vary significantly depending on the presence or absence of tumors, which has been extensively studied from 1980 to the present [8-9]. These properties are characterized by permittivity and tangent loss, with different tissues exhibiting distinct values at various frequencies. Table 1 presents the material properties of a breast tissue model derived from previous literature [10].In the design of the 3D breast model, considerations include skin, fibrous tissue (fibro), fat, and glandular tissue. Figure 1 illustrates a basic representation of the 3D breast tissue model, and its dimensions are detailed in Table 2.

Table 1 Electrical material property of breast tissue.

Frequency Range, GHz	Tissues	Permittivity ε_r	Tangent Loss $\tan\delta$
30-38 GHz	Skin	17.7	0.93
30-38 GHz	Fat	3.4	0.16
30-38 GHz	Fibro Glandular	16	0.94
30-38 GHz	Tumor	18	1.05

Figure-1: Structure of Breast Tissue Model Table 2 Breast Tissue model dimensions.

Tissues	Dimensions
Breast Skin Radius	12mm
Fat Radius	11mm
Fibro Glandular Radius	10mm
Areola Radius	1mm
Tumor Radius	1mm

III. DESIGN OF PATCH ANTENNA

Patch antennas are compact and efficient communication devices widely utilized in radio frequency (RF) and microwave applications. This study focuses on the rectangular patch antenna structure, chosen for its affordability and compactness, ideal for potential integration into microwave imaging systems. The initial design of a millimeter-wave antenna involves several key steps [11-12]. Initially, a resonant frequency of 33 GHz was selected, with RT/duroid 5880LZ chosen as the dielectric material for the substrate. The necessary dimensions were calculated using specific equations (1), (2), and (3), and these details are provided in Table 3. Subsequently, the dimensions were simulated using the HFSS electromagnetic (EM) simulator.

An iterative parametric study was then conducted to achieve the desired performance outcomes.

$$W_p = \frac{c}{2f_c}\sqrt{\frac{2}{2\varepsilon_e + 1}} \qquad (1)$$

$$\varepsilon_{ref} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2\sqrt{1 + 12\frac{h}{W_P}}} \qquad (2)$$

$$L_p = \frac{c}{2f_c}\sqrt{\frac{2}{\varepsilon_{ref}}} \quad (3)$$

Table 3 Dimensions of SMWA.

Variables	Ls	Ws	Lp	Wp
Dimensions	6*mm*	6*mm*	2.02*mm*	3.12*mm*
Variables	Lf	Wf	h	
Dimensions	2.1*mm*	0.4*mm*	0.5*mm*	

The single millimeter-wave antenna (SMWA) structures were designed and connected via a 50Ω microstrip line, as shown in Figure 2. The top view illustrates the patch element positioned above the RT/duroid 5880LZ substrate, highlighting its configuration and placement. The ground view depicts the ground plane, which is essential for the antenna's operation and performance. This design ensures optimal transmission and reception of millimeter-wave signals, crucial for applications in high-frequency communication and imaging systems.

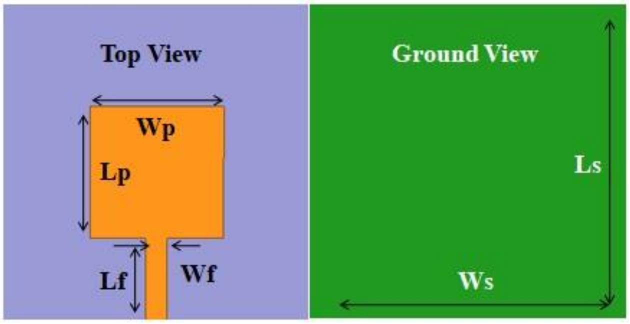

Figure-2: Structure of SMWA

IV. SIMULATION SCENARIOS

The simulation considers three different scenarios: a breast without a tumor, a breast with a tumor, and tumors located in various positions, as depicted in Figure 3. This approach allows for comprehensive testing of the antenna's performance under different conditions, providing insights into its ability to detect and localize tumors effectively.

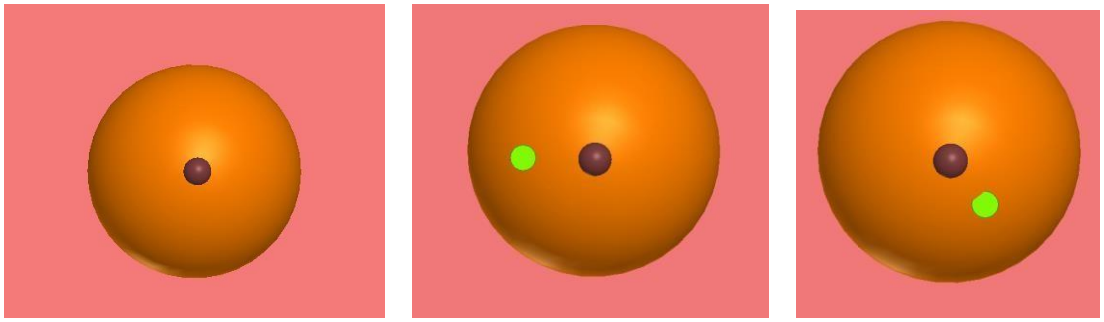

Figure-3: Simulation scenarios; (a) breast without tumor, (b) breast with tumor and (c) tumor in different position.

The configuration of four single millimeter-wave antennas (SMWA) arranged at 90 degrees around the breast tissue model is illustrated in Figure 4. In the first scenario, breast tissue without any tumors was positioned at the center of the four antennas, and the simulation was carried out. In the second scenario, the setup remained the same, but a tumor with a 1 mm radius was introduced into the breast tissue. In the final scenario, the breast tissue containing the tumor was rotated by 45 degrees, and the simulation was performed to evaluate the impact of the positional change on the detection capabilities.

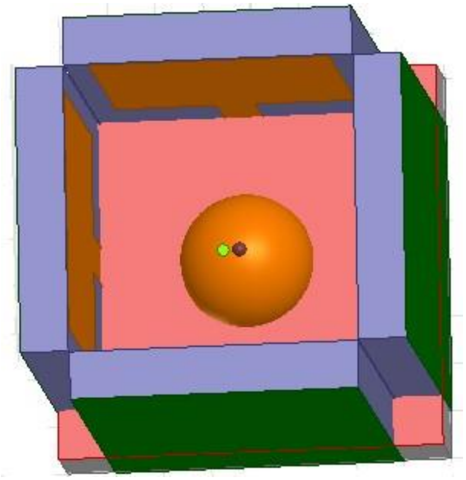

Figure-4: Arrangement of Four Antennas with breast tissue model

V. RESULTS AND DISCUSSIONS

The designed single millimeter-wave antennas (SMWA) and the breast tissue model were simulated using a commercially available HFSS electromagnetic simulator. A crucial parameter for assessing antenna performance is the return loss, which is characterized by the scattering parameter S11. The S11 characteristics of the SMWA were computed and are presented in Figure 5. At the operating frequency of 33 GHz, the SMWA demonstrated a return loss of -19.33 dB, indicating a strong signal reflection and efficient performance. Furthermore, the antenna achieved a bandwidth of 2.10 GHz, where the return loss remains below -10 dB. This wide bandwidth is essential for high-resolution imaging applications. The design also ensures proper impedance matching, which enhances the radiation efficiency and overall effectiveness of the antenna system.

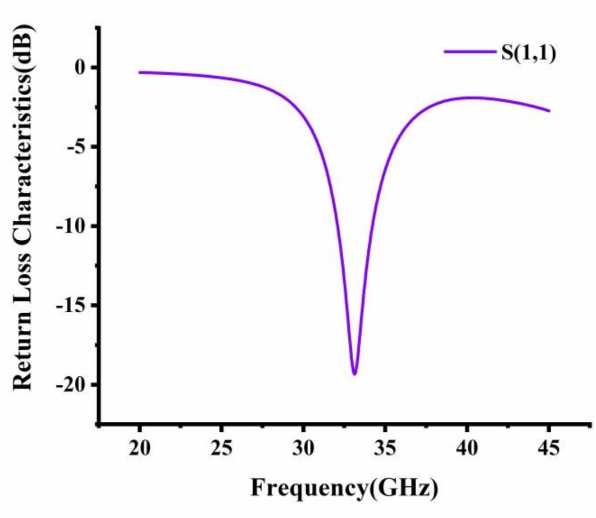

Figure-5: Return Loss Characteristics of SMWA

The Voltage Standing Wave Ratio (VSWR) is a critical parameter, especially in millimeter-wave antenna configurations. VSWR measures the compatibility between an antenna and its transceiver device by assessing the mismatch between transmitted and reflected waves [10]. A high VSWR indicates poor impedance matching, which can degrade the signal quality. Conversely, a low VSWR signifies efficient signal transmission and reception. As depicted in Figure 6, the millimeter-wave antenna demonstrates a VSWR of 1.2, indicating excellent impedance matching and efficient performance.

The radiation pattern is a crucial aspect of antenna performance, particularly in medical imaging applications where precision and clarity are paramount. In Figure 7, the radiation pattern of the single millimeter-wave antenna (SMWA) demonstrates waves extending to the far field, showcasing broadside radiation characteristics. This type of radiation pattern is especially beneficial for medical imaging as it provides uniform coverage and consistent signal strength across the imaging area. Broadside radiation ensures that the electromagnetic waves are directed perpendicularly to the surface of the antenna, allowing for deeper penetration into biological tissues. This is vital for accurately capturing high-resolution images of internal structures, such as detecting tumors in breast tissue or abnormalities in other organs. The uniformity and directionality of the broadside radiation pattern enhance the clarity and detail of the medical images, making the SMWA an effective tool for diagnostic imaging. By minimizing signal loss and maximizing the depth of penetration, this antenna design supports the precise detection and localization of medical conditions, thereby improving diagnostic accuracy and patient outcomes.

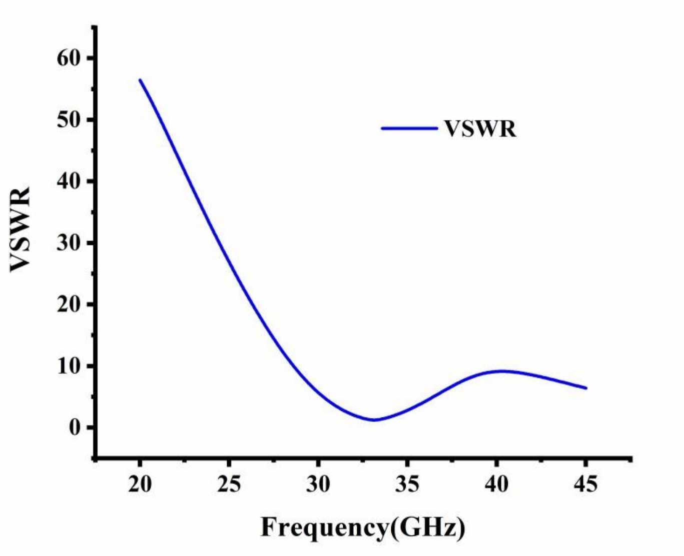

Figure-6: VSWR of SMWA

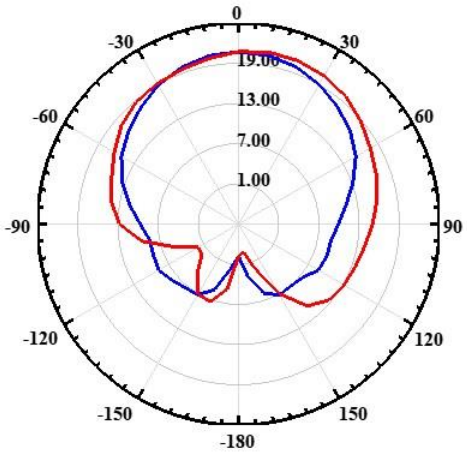

Figure-7: Radiation Pattern of SMWA

The coverage area and link budget of a single millimeter-wave antenna (SMWA) are significantly influenced by its Total Peak Gain (TPG) [11]. In medical imaging applications, a high TPG is crucial as it directly impacts the quality and resolution of the captured images. Figure 8 illustrates a TPG of 7.07 dB, indicating the antenna's efficiency in directing energy towards the target area. A TPG of 7.07 dB ensures that the SMWA can effectively transmit and receive signals with minimal loss, which is essential for penetrating biological tissues and obtaining clear medical images. In practical terms, this high gain enhances the antenna's ability to detect fine details within the body, such as small tumors or other abnormalities. The improved signal strength and clarity afforded by a high TPG result in more accurate diagnostic imaging, enabling healthcare professionals to identify and treat conditions at an earlier stage. This is particularly beneficial in breast cancer screening, where early detection can significantly improve treatment outcomes. The robust performance of the SMWA, as indicated by its TPG, underscores its potential as a valuable tool in advanced medical imaging technologies.

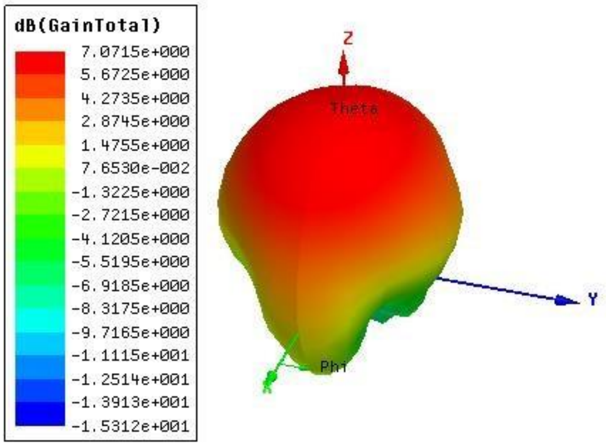

Figure-8: Total Peak Gain Pattern of SMWA

Based on the results obtained from the single millimeter-wave antenna (SMWA) simulations, a configuration of four SMWAs was arranged at 90 degrees around the breast tissue model. The return loss characteristics versus frequency were recorded for three different scenarios: a breast without a tumor, a breast with a tumor, and a breast with a tumor positioned at various locations. These scenarios are depicted in Figure 9.The simulations considered these three distinct conditions to evaluate the antenna's performance. The ideal resonant frequency of the antenna, initially set at 33 GHz, significantly shifted to 34.5 GHz upon detecting a 1 mm tumor cell within the breast phantom. Figure 9 illustrates how the resonant frequency varies when the tumor is positioned differently within the breast tissue. This shift in frequency indicates the antenna's sensitivity to the presence and location of the tumor, demonstrating its potential effectiveness for early-stage tumor detection. The ability to detect such small tumors and observe changes in resonant frequency highlights the SMWA's suitability for precise and accurate breast cancer diagnostics. Table 4 illustrates how the frequency varies as the tumor's position changes within the breast phantom model. This data provides insights into how the antenna's resonant frequency shifts in response to different tumor locations, offering valuable information for optimizing the antenna's performance in detecting and localizing tumors within breast tissue. Understanding these frequency variations is crucial for enhancing the antenna's sensitivity and accuracy in medical imaging applications, particularly in early-stage breast cancer detection.

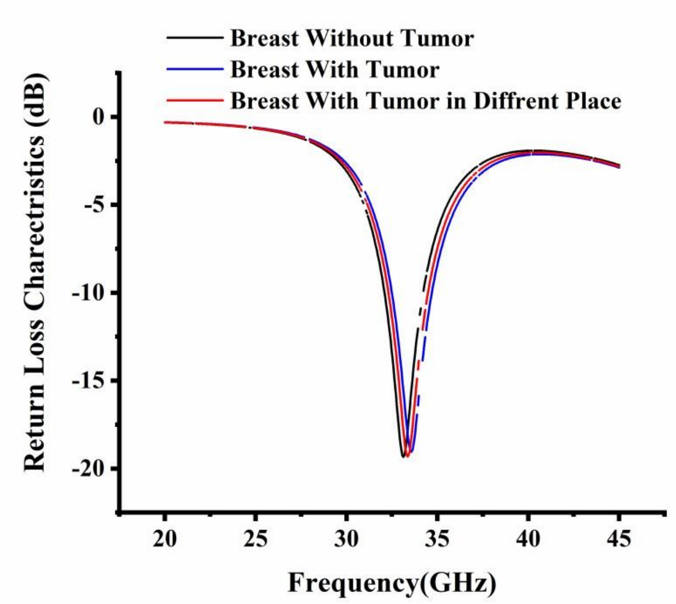

Figure-10: Different Situation Return Loss Characteristics of SMA

Table 4 Shifted Resonant Frequencies with Tumor Position

Tumor Position	Resonant Frequency (GHz)	Return Loss (dB)
Breast without tumor	33GHz	-19.33dB
Breast with tumor	34GHz	-20.18dB
Breast with tumor in different place	34.5GHz	-16.75B

VI. CONCLUSION

The global increase in breast cancer cases highlights the critical need for effective diagnostic tools. To address this, a cost-effective mmWave antenna sensor was designed on 'Roger RT 5880' substrate using HFSS simulation. This compact antenna (2.45 × 2.5 mm^2) operates at 33 GHz with a bandwidth of 2.10 GHz, offering high gain (7.07 dB) and low VSWR (1.2), enabling detection of 1 mm-sized breast tumors. Deploying four antennas at different angles allows precise localization of tumors by analyzing S-parameter data. With its high gain and efficient radiation, the antenna is suitable for microwave imaging and 5G communication systems, promising advancements in breast cancer diagnosis and treatment. Its versatility and performance make it valuable across medical and technological applications, potentially enhancing patient outcomes and quality of life.

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REFERENCES

1. S. S. Chaudhary, R. K. Mishra, A. Swarup, and J. M. Tomas, “Dielectric properties of normal & malignant human breast tissues at radio wave & microwave frequencies,” Indian Journal of Biochemistry and Biophysics, vol. 21, no. 1, pp. 76–79, 1984.
2. R. L. Siegel, K. D. Miller, and A. Jemal,(2016) ‘‘Cancer statistics, 2016,’’ CA Cancer J. Clin., vol. 66, no. 1, pp. 7–30, 2016.
3. E. C. Fear, J. Bourqui, C. Curtis, D. Mew,(2013) ‘‘Microwave breast imaging with a monostatic radar-based system: A study of application to patients,’’ IEEE Trans. Microw. Theory Techn., 61(5), 2119–2128.
4. Di Meo, S., Espín-López, P. F., Martellosio (2017). On the feasibility of breast cancer imaging systems at millimetrewaves frequencies. IEEE Transactions on Microwave Theory and Techniques, 65(5), 1795-1806.

5. M. T. Bevacqua, S. Di Meo, L. Crocco, (2021) ‘‘Millimeter-waves breast cancer imaging via inverse scattering techniques,’’ IEEE J. Electromagn., RF Microw. Med. Biol., 5(3), 246–253.
6. M. Lenin Kumar, (2019)“A design of Novel Hybrid Opto-acoustic Modem for Underwater Communication”, International Journal of Innovative Technology and Exploring Engineering,8(8),2278-3075.
7. M. K. Sharma, M. Kumar, J. P. Saini,(2020) ‘‘Experimental investigation of the breast phantom for tumor detection using ultra-wide band–MIMO antenna sensor (UMAS) probe,’’ IEEE Sensors J.20(12),6745–6752.
8. S. Subramanian, B. Sundarambal, and D. Nirmal, (2018) ‘‘Investigation on simulationbased specific absorption rate in ultra-wideband antenna for breast cancer detection,’’ IEEE Sensors J. 18(24), 10002–10009.
9. Syed, A., Sobahi, N., Sheikh, M., Mittra, R. (2021). Modified 16-quasi log periodic antenna array for microwave imaging of breast cancer detection. Applied Sciences, 12(1), 147.
10. Mirbeik-Sabzevari, A., & Tavassolian, N. (2019). Tumour detection using millimetrewave technology: Differentiating between benign lesions and cancer tissues. IEEE Microwave Magazine, 20(8), 30-43.
11. Kaur, M., & Goyal, S. (2020). Microstrip patch antenna design for early breast cancer detection. International Journal of Recent Technology and Engineering (IJRTE), 8(6), 8.
12. A. Balanis, “Antenna Theory”, *IEEE Transactions on Antenna and Propagation,* 1992; 41(9):7-23.