Journal of Engineering and Technology for Industrial Applications

ISSN ONLINE: 2447-0228

ITEGAM-JETIA

Manaus, v.12 n.58, p. 224-234. March/April, 2026.
DOI: https://doi.org/10.5935/jetia. v12i58.2987

RESEARCH ARTICLE | OPEN ACCESS

LEVERAGING TUMOR INDUCED FREQUENCY SHIFTS BY A 24 GHZ MICROSTRIP ANTENNA WITH HIGH SENSITIVITY FOR BREAST CANCER DIAGNOSIS

Yaqdhan Mahmood Hussein*[1], Baydaa Hadi Saoudi[2], Thulfiqar H. Mandeel[3], Tabarek Alwan Tuib[4]

[1]Dept. of Electronics and Communications Engineering, College of Engineering, Al-Muthanna University, Al-Muthanna, Iraq.
[1]Advanced RF and Microwave Research Group (ARFMRG), Communication Engineering Department,Faculty of Electrical Engineering, University Teknologi Malaysia, 81310 UTM Johor Bahru, Johor, Malaysia.
[2]Dept. of Information and communications technology, Technical Institute of Samawah, Al-Furat Al-Awsat Technical University, Najaf, Iraq.
[3]Dept. of Oil and Gas Engineering Techniques, Petroleum and Energy Engineering Technical College, Al-Furat Al-Awsat Technical University, Najaf, Iraq.
[4]Departamento de Engenharia Eletrônica e de Comunicações, Faculdade de Engenharia, Universidade Al-Muthanna, Al-Muthanna, Iraque.
[4]Faculdade de Engenharia, Universidade Al Ayen, Nasiriyah 64001, Iraque.

[1]https://orcid.org/0000-0001-7153-4120, [2]https://orcid.org/0009-0007-2898-7846,
[3]https://orcid.org/0000-0003-1270-0891, [4]https://orcid.org/0000-0002-1646-0015

Email: *yaqthanm79@gmail.com, ins.byd44@atu.edu.iq, thulfiqar.mandeel@atu.edu.iq, tabarcka@gmail.com

ARTICLE INFO

Article History
Received: November 21, 2025
Reviewed: January 21, 2026
Accepted: January 29, 2026
Published: March 31, 2026

Keywords:
Microstrip antenna;
Biomedical;
Breast Cancer Detection.

ABSTRACT

Early detection of breast cancer is critical for patient survival, yet current gold-standard methods like X-ray mammography present significant limitations, including ionizing radiation. a new design of the microstrip patch antenna that is optimized towards early detection of breast cancer at 24 GHz through the benefits of millimeter-wave imaging, such as high resolution and non-ionizing radiation. The cross-slot method has been used with Rogers RT 5880 substrate which in the free space has shown good performance of 10 dB, efficiency of 95% and a wide bandwidth of 1.3 GHz (S11 < -10 dB from 22.8-24.1 GHz). The design was tested in three critical conditions using CST Microwave Studio simulation that included free space operation, multilayer human tissue (skin, fat, fibro) integration, and tumor-embedded conditions. Findings indicate the clear tumor signatures as a frequency shift of 700 MHz, bandwidth reduction to less than 3 MHz and radiation pattern distortions (beam splitting in multiple co-polarized lobes and increased backscatter). It is worth noting that tissue integration decreased gain to 9 dB, but tumor detection sensitivity (90% efficiency) was increased (through an increase in energy coupling) by high permittivity of the tumor. These quantifiable electromagnetic perturbations offer a viable, non-invasive substitute to traditional mammography, and have shown great potential to wearable diagnostic systems in form of the compact design, high sensitivity tumor and real-time monitoring. The paper takes microwave breast imaging one step further and determines definite correlations between changes in the parameters of the antennas and the presence of the malignant tissues.

I. INTRODUCTION

Microstrip antennas have become one of the potential technologies in medical diagnostics especially in breast cancer detection. They are lightweight, compact, and can be easily incorporated into a wearable device hence suitable in non-invasive medical applications. The main benefit of using microstrip antennas is that they can be used in microwave frequencies which makes them provide high-resolution imaging and accuracy in detecting abnormalities breast tissues. In recent years, researchers have focused on developing microstrip antennas specifically designed for microwave breast imaging. This technique offers a safer and more accurate alternative to traditional methods like X-ray mammography, ultrasound, and MRI.

By placing the antenna in contact with the breast skin, the effects of backscattering are reduced, enhancing the sensitivity of tumor detection [1], [2]. Slotted waveguide antennas are one type of antenna. It has several applications, great handling capabilities, and the ability to boost gain and power. Due to its size, the waveguide structure necessitated challenging transitions in order to connect to planar circuitry. The transitions needed for integrating rectangular waveguides with planar circuitry are expensive and large. A fairly new type of planar transmission line called a substrate integrated waveguide (SIW) incorporates a waveguide into planar circuit, like a printed circuit board or a low temperature co-fired ceramic. SIW combines the advantages of rectangular waveguides, such as the power is higher handling capacity low loss and high Q-factor, into planar circuitry, in addition, SIWs license for simple transition between the other planar transmission lines and they are small, have a low-profile and weigh less compared to the rectangular waveguides.

Substrate Integrated Waveguide (SIW) technology retains the fundamental electromagnetic characteristics of traditional rectangular waveguides (RWG), including high quality factor (Q), low radiation loss, and excellent power-handling capabilities, while enabling planar integration. This allows direct transfer of established RWG design methodologies to SIW platforms, such as TE_{m0} mode excitation, impedance matching techniques, and cavity resonance principles. Major RWJ-derived parts such as waveguide dividers, bandpass filters, and slot array antennas, have been miniaturized successfully in SIW configurations with similar performance [3]. As an example, SIW filters will have <0.5 dB insertion losses at Ka-band, comparable to metallic waveguides. It is specifically useful in radar and communication applications that need strict beamforming because the inherent geometry of SIW allows narrow-beam radiation patterns (beamwidth of less than 30°) with sidelobe suppression of over 20 dB.

Unlike RWGs, SIW structures facilitate seamless integration with planar circuits through microstrip-to-SIW transitions, eliminating bulky coaxial adapters. Recent advances in 5G mmWave systems (24–40 GHz) leverage SIW's shaped-beam capabilities for base station antennas, where its 0.1–0.3 dB/cm loss at 28 GHz outperforms microstrip alternatives. Additionally, SIW's compatibility with PCB fabrication reduces costs by 60–80% compared to machined RWGs, making it ideal for mass-produced phased arrays. However, design challenges persist in suppressing higher-order modes (TE_{20}) when scaling to frequencies >60 GHz, requiring optimized via fencing ($d/p < 0.5$, where d=via diameter, p=pitch) to mimic perfect magnetic walls. Compared to other cancers, breast cancer is the most common type among women, particularly in those over 40. According to American statistics from 2013, out of 232,340 cases reported, 64,640 cases are in situ, and 39,620 cases resulted in death, indicating that women are at a significant risk of developing breast cancer [4].

The use of microstrip antennas in this context not only improves the accuracy of early-stage breast cancer detection but also provides a more comfortable and convenient experience for patients. The integration of microstrip antennas into medical devices represents a significant advancement in the fight against breast cancer. Their ability to provide detailed imaging and real-time monitoring makes them a valuable tool in early diagnosis and treatment, potentially increasing survival rates and improving patient outcomes4. As research continues to advance, the role of microstrip antennas in medical diagnostics is expected to grow, offering new possibilities for non-invasive and effective cancer detection. The three primary methods utilized for tumor diagnosis and detection in the past ten years are mammography, ultrasound, also magnetic resonance imaging (MRI), although they still have many drawbacks [4]. In order to achieve ultra-wideband antennas with the highest efficiency and precision possible, researchers are frequently considering developing antenna designs for defense as well as medical applications [4].

According to the Federal Communications Commission's (FCC) 2004 guidelines, UWB antennas operate in the frequency range of 3.1 to 10.6 GHz; also, the antenna's weight and size are crucial design elements [5]. In In this study, we design and optimize a microstrip patch antenna operating at 24 GHz for breast cancer detection applications. The antenna's performance is comprehensively evaluated through three critical scenarios: (1) radiation characteristics in free space as a baseline measurement, (2) operation when integrated with multilayer human tissue (skin, fat, and muscle), and (3) detection capability when malignant tumor tissue ($\varepsilon_r \approx 60$) is embedded within the normal tissue structure. We examine important parameters such as reflection coefficient (S_1), radiation patterns, gain and efficiency under these conditions by simulating them in CST Microwave Studio using full-wave electromagnetic simulations.

II. RELATED WORK

The development of antennas with better performance in performance using vital measures such as reduced return loss (S11), wide bandwidth, increased gain, and high efficiency is key to this study [1-7]. A low S11 value is important because it means that a large percentage of the transmitted power is sent to the breast tissue which is critical in effective signal penetration and hence reflection. The wide bandwidth provides the ability to characterize tissues thoroughly and possibly differentiate healthy and cancerous tissues better, and high gain ensures that the signal transmission and reception are robust. Efficiency of the antenna, however, is the key element to reducing the energy loss and maximizing the amount of power emitted into the target and hence overall detection sensitivity is maximized [1-7].

New methods in the design of microstrip antennas include the choice of materials of the substrate including flexible polyamide used in the making of wearable antennas and the geometry of the antennas to achieve the best performance based on the specific diagnostic intended use [3]. Research has shown that designs can work with a frequency in the range of 33 GHz, with encouraging results in S11, and the ability to sense the presence and location of tumors by changing S-parameters [2]. High-level electromagnetic simulation, typically by using software such as HFSS, is important in all antenna design behavior prediction and optimization before physical fabrication [3]. To validate the usefulness of the proposed designs in real-life situations, the simulations are often supplemented with experimental validation, often using detailed breast phantoms [4]. Table I relates to the various papers concerning cancer breast microstrip antenna.

III. LIMITATIONS OF CONVENTIONAL BREAST CANCER IMAGING TECHNOLOGISE

Various approaches are already available and effective in imaging in search of early detection of breast cancer including Breast Self-Examination (BSE), Clinical Breast Examination (CBE), Breast Ultrasound, Computerized Tomography (CT), Magnetic Resonance Imaging (MRI), Positron Emission Tomography (PET), and Mammography. Nevertheless, each of these methods have serious shortcomings.

As an example, PET cannot work with primary tumors, whereas Mammography, which is regarded as the gold standard in breast screening, does not work in young women and dense-breasted women. Moreover, Mammography uses ionizing radiations, is slow in imaging and not portable.

Table 1: Related Work of Microstrip Antenna of Cancer Breast.

Ref	Method	Freq GHz	Gain dB	Weak Points
[8]	focuses on design of a microstrip patch antenna.	2.45	3	Conventional methods like X-ray, MRI, and ultrasound have limitations.
[9]	Four antenna structures were placed around the breast in simulations to analyze S-parameter changes.	33	2	Not explicitly stated in the provided snippet.
[10]	Designed a flexible microstrip patch antenna operating at 2.45 GHz using polyamide material	2.45	1	Low gain, and miss matching
[11]	detect malignant tumors using 3D breast phantoms,	ISM band	2.5	Traditional techniques like X-ray mammograms, MRI, ultrasound,
[12]	comparing designs based on substrate, feeding techniques, SAR, E and H field, Return Loss,	N/A	1.55	The paper highlights the limitations of existing techniques like mammography (ionizing radiation),
[13]	review article summarizing various microwave approaches for breast tumor detection	7-28	10.5	Traditional methods have drawbacks like high costs, radiation exposure, and patient inconvenienc.

Source: Authors, (2026).

X-ray techniques, including CT scan, may destroy cells and tissues and MRI has difficulty in imaging of superficial soft tissues because of the limitation in the sensitivity of magnetic rays. A comparative study of these methods, as reported in [14], further brings into focus their advantages and disadvantages as shown in Table 2 [14]. These restrictions bring into focus the fact that there is a need to develop better imaging technologies which can result in better detection of breast cancer at an early stage. Table II indicate the comparatives of breast cancer.

Table 2: Related Work of Microstrip Antenna of Cancer Breast.

Category	Method	Advantages	Limitations
Examination-based	Breast Self-Examination (BSE)	Convenient for high-risk groups; easy to perform.	No proven impact on mortality; potential for harm if misinterpreted.
	Clinical Breast Exam (CBE)	Can reduce mortality rates through early intervention.	Cannot confirm malignancy; limited diagnostic.
Imaging-based	Mammography	Fast imaging time; high resolution; portable equipment.	Uses ionizing radiation; ineffective for younger women and dense breast tissue.
	Breast Ultrasound	Noninvasive, widely available, low-cost, and painless.	Low resolution and contrast; results depend on operator skill.
	Positron Emission Tomography (PET)	Provides functional/structural details; excellent contrast.	Slow imaging; non-portable; involves ionizing radiation.
	Breast MRI	High spatial resolution; no radiation; effective for detecting cancer spread.	Slow imaging; non-portable; limited to lateral views; complex interpretation.

Source: Authors, (2026).

Microwave Imaging (MI) has become a very promising substitute to the traditional breast cancer detecting techniques, which overcomes most of the drawbacks mentioned in Section III. There are a few remarkable benefits associated with this innovative method: the technique is cost-effective, non-ionizing radiation, it is highly sensitive in tumor detecting and makes the examination procedure comfortable to the patient. Microstrip patch antennas are the building blocks of the MI system used as the detectors. Present day imaging technologies of microwaves are mainly divided into two different methodologies:

- Tomography-based imaging
- Radar-based imaging

A typical Microwave Imaging (MWI) system configuration includes:

- A microwave transmitter that emits carefully controlled signals into breast tissue
- A sensitive receiver system that detects and analyzes backscattered signals

The basic principle of operation MWI as demonstrated in Figure 1 is based on the fact that the dielectric contrast between the malignant tumor tissue and normal breast tissue is measurable. The interaction of microwave signals with breast tissue causes different scattering patterns of tumorous regions because they have varying dielectric traits. These are captured and analyzed to detect possible malignancies with a high level of accuracy.

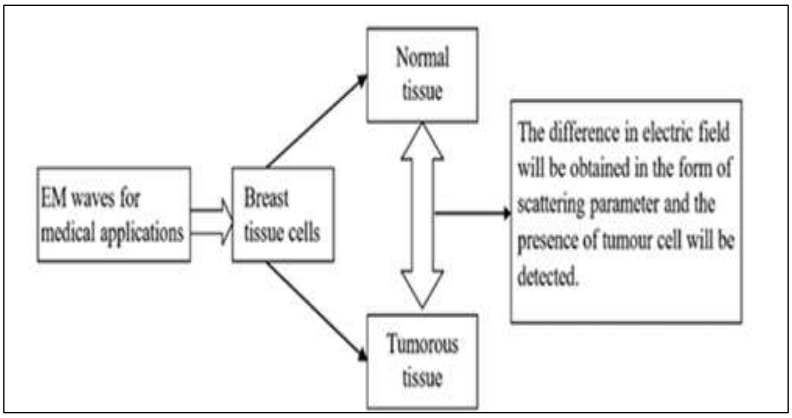


Figure 1: Principle of Microwave Breast Cancer Detection Using EM Wave Scattering.
Source: Authors, (2026).

IV. PERFORMANCE-OPTIMIZED PATCH ANTENNAS FOR MEDICAL SYSTEMS

Microstrip patch antennas have become a key technology in biomedical applications in that they are compact, they are lightweight, and can be used with wearable systems. Such antennas are being used more and more in medical implants, wireless health and in microwave imaging systems. Another pioneering work was done by [8] who created a Multiple Ring Slot Ultra-wideband (MRS-uWB) antenna that was created on FR-4 substrate and its entire operational bandwidth was 2 to 12 GHz. The antenna achieved a high level of return loss of lower than -30 dB throughout the UWB frequency range through novel design methods of partial ground plane structuring, optimization of rectangular slots in the feed line, and enabled it to be especially applicable to broadband biomedical systems. On this basis [15] designed a specialized two sleeve antenna with the ISM band (2.45 GHz).

This design gave a return loss of more than -10 dB by means of careful optimization of sleeve lengths and ground plane dimensions. The effectiveness of the antenna was also confirmed by experiments that were performed on tissue-equivalent material of a human being; this demonstrated that the antenna could be used in biomedical applications. In the case of wearable medical devices, a comparative study of textile-based substrates, such as jean cotton, Teflon and traditional FR-4, was carried out in-depth by [9] with further insight into the comparative analysis. Their study showed that Teflon substrates were the best with return loss value of between -13.93 and -19.39 dB at 2.4 GHz and were also very flexible. Likewise [10] also experimented with cotton and jean substrates to support on-body communication, and developed new methods to assemble adhesive tape antennas with a return loss of less than -10 dB at 2.45 GHz.

Table 3: Microstrip Patch Antennas for Biomedical Application.

Ref	Substrate(s)	Feed Type	Freq (GHz)	S11 (dB)	Flexibility	Design Features
[8]	FR-4	Microstrip	2–12 (UWB)	< -30	No	Multiple ring slots, partial ground
[15]	FR-4	Microstrip	2.45 (ISM)	< -10	No	Two-sleeve design, low profile
[9]	Jean Cotton/Teflon/FR-4	Coaxial	2.438–2.452	-13.93 to -19.39	Yes	Textile substrates, multi-material comparison
[10]	Cotton/Jean	Microstrip	2.45	< -10	Yes	Adhesive tape assembly, on-body use
[11]	Jean	Microstrip	2.24	-15.52 to -24.10	Yes	Array design, hidden in fabric
[12]	Teflon/Felt/Jean	Coaxial	2.42	-18 to -23	Yes	Double substrate with DGS

Source: Authors, (2026).

By [11] made progress in array designs with a two-element textile antenna array being developed on jean substrate. This design had a high-performance (-24.10 dB return loss) than the single-element antennas, and it is wearable. [12] even extended further and explored the double substrate arrangement with the use of Teflon and felt materials that had defect ground structures (DGS). The optimized structure had the highest return loss of -23 dB at 2.42 GHz, which illustrates the high-performance wearable medical monitoring systems. All these studies have shown that microstrip patch antennas have developed progressively over time to be used in biomedical applications with the most important factors considered in their design such as the choice of substrate, structural adjustments, and array designs. The study highlights the need to balance technical performance indicators with practice-based demands like flexibility, convenience, and biocompatibility to be successfully introduced in healthcare systems. In table 3 main parameters of antenna have been stated.

V. CURRENT DETECTION METHODS

Conventional breast imaging techniques like mammography, magnetic resonance imaging (MRI), and X-ray are highly efficient and sensitive in tumor detection, however, many women are not keen on using such techniques because they require breast compression or exposure of breast tissue to harmful radiation [16]. Microwave imaging modalities are new alternatives to the conventional methods that have a great potential in breast tumor detection. The existing microwave imaging methods, particularly those based on microstrip antennas, can be roughly categorized as transmission-based and reflection-based methods. The proposed method in this work is a planar array-based reflection-mode (or monostatic) near-field breast imaging technique.

The breast is a convex and inhomogeneous object. To provide good coverage of the breast under test and accommodate people with various breast sizes, it would be difficult to select fixed positions for the antennas because the antennas at the selected positions could not achieve a satisfactory SNR (signal-to-noise ratio). As such, a robot scanner is designed to move the planar array on a plane. This plane is right above the breast and parallel to it, which is named the near-field scanning plane. Consequently, the existing imaging methods cannot be directly extended because they are all based on far-field assumption, which does not hold true in this new imaging scenario.

The proposed method is thus a near-field imaging method to focus the scattered field data to obtain image of the breast under test. It is desirable to employ an antenna array to detect the tumor or any abnormalities in breast tissue. The tumor is considered as point target or lumped target to be detected using a back-propagation (BP)-based algorithm. The array is modeled as a uniform planar array consisting of N x N [17] regularly spaced antennas for UWB (ultra-wide) breast cancer detection. Genetic algorithms are adopted to design finite-sized arrays with discrete element numbers that can achieve a balanced pattern. The dielectric properties of breast tissues are determined and modeled at microwave frequencies.

VI. DESIGN METHOD OF ANTENNA BASED ON MICROSTRIP TECHNOLOGY

The majority of wireless systems, in printed circuit technology, use microstrip or printed patch antennas. Microstrip or patch antennas are used in wireless communication applications and are designed for transmitting and receiving electromagnetic energy in microwave range. Orthogonal cross slot shaped perturbation is etched at the current-maximum region of a rectangular microstrip patch to (i) split/merge close resonant modes, (ii) extend the effective surface current path, and (iii) increase shunt capacitance. Together, these actions broaden impedance bandwidth and stabilize radiation efficiency at 24 GHz while preserving a compact footprint on RT/Roger-5880 ($\varepsilon_r \approx 2.2$, tan $\delta \approx 0.0009$). When the antenna is electromagnetically loaded by breast tissues, The geometry regarding the printed patch [18] and the properties of the substrate that the antenna is printed onto determine how well a microstrip antenna works and operates. The conversional structure of microstrip antenna is shown in Figure 2 [19].

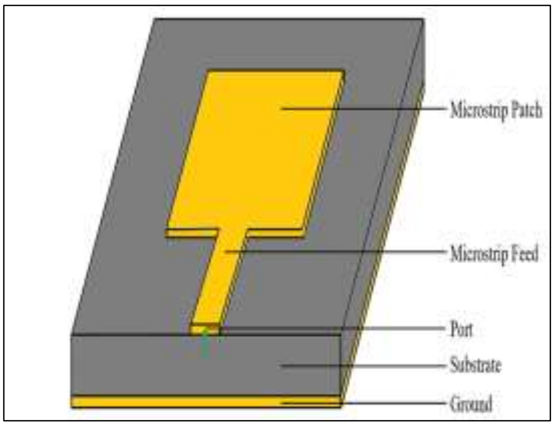


Figure 2: Conversional structure of microstrip antenna.
Source: [18].

Where c is speed of light:

$$W = \frac{c}{2f_r}\sqrt{\frac{2}{\epsilon_r + 1}} \tag{1}$$

To find effective parameters:

$$\epsilon_{reff} = \frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2}\left[1 + 12\frac{h}{w}\right]^{-1/2}, \frac{w}{h} > 1 \tag{2}$$

$$\frac{\Delta L}{h} = 0.412\frac{(\epsilon_{reff} + 0.3)\left(\frac{w}{h} + 0.258\right)}{(\epsilon_{reff} - 0.258)\left(\frac{w}{h} + 0.8\right)} \tag{3}$$

To Get patch length:

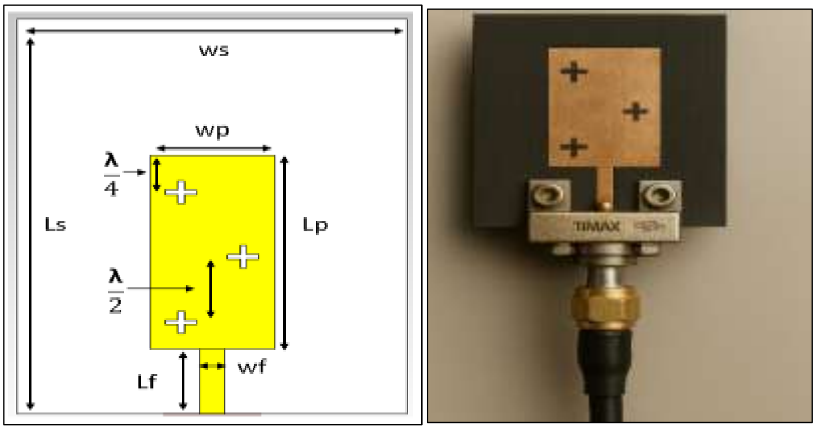
$$L = \frac{c}{2f_r\sqrt{\epsilon_{reff}}} - 2\Delta L \tag{4}$$

VII. MATERIALS AND METHODS

VII.1 ANTENNA DESIGN METHODOLOGY AND SUBSTRATE SELECTION IN FREE SPACE

The initial phase of this research involved designing a cross-slot microstrip patch antenna operating in free space, as illustrated in Figure 3(a). Careful consideration was given to substrate selection, with common materials like FR4 ($\varepsilon_r \approx 4.3$, tan $\delta \approx 0.02$) and various Rogers RT series substrates evaluated for their dielectric properties. The use of Rogers RT 5880 substrate, specifically, is based on its best combination of low dielectric constant ($\varepsilon_r = 2.2 \pm 0.02$), very low loss tangent (tan $\delta = 0.0009$), and uniform thickness (0.508 mm)-values, which play a great role in improving the performance of antenna at millimeter-wave frequencies. The substrate is completely coated with an electrolytic copper ground plane of 0.035 mm thickness (1 oz/ft²) and this offers a high degree of conductivity and structural integrity.

The antenna dimensions such as patch width (W_p = 8 mm), length (L_p = 17.2 mm), feedline size (Wf = 1.57 mm, Lf = 5.75 mm) and slot positioning is also calculated with the use of transmission line models as well as optimized on a parametric basis in CST Microwave Studio. These dimensions parameters, completely tabulated in Table III were calculated to give optimal impedance matching and radiation aspects at the target 24 GHz of operational frequency and the cross-slot configuration was used to optimize bandwidth and radiation efficiency essential attributes to successful breast tissue interrogation in subsequent detection stages. Table 4 Refer to the all dimensions of antenna, figure 3(b) refer to the fabricated antenna.



(a) (b)

Figure 3: The proposed design with cross slot, (a) simulated, (b) fabricated.

Source: Authors, (2026).

Table 4: Refer To the All Dimensions of Antenna.

Sample	Full name	Value mm
Wp	Width of patch	8
Lp	Length of patch	17.2
Ws	Width of substrate	25
Ls	Length of substrate	35
Wf	Width of feedline	1.57
Lf	Length of feedline	5.75

Source: Authors, (2026).

VII.2 INTEGRATION OF ANTENNA

After the free-space characterization of cross-slot antenna, two antennas have been integrated in free space as transmit and revived antenna as shown in figure 4, to check the reflection coefficient and insertion loss of transmit antenna at certain frequency. The paper went on to analyze the performance of the antenna in the presence of a breast. CTS microwave studio modeled three layers of critical biological layering (skin, muscle, and fat) with a dielectric brick structure with the corresponding material properties to sufficiently model the electromagnetic interactions. Figure 5 represents the first model that has the spatial relation between the antenna and the tissue layers with an air gap, final integrated model where the antenna and the breast are in direct contact with tissue stack. Each layer was assigned frequency-dependent dielectric properties based on established biological data: as shown in table 5. Variations in the scattering parameters can be compared with the introduction of malignant tissue. The integration procedure was a close consideration of anatomical proportions of thickness of the layers and also proper impedance matching at the antenna-tissue interface in order to maximize the signal penetration and reflection behavior.

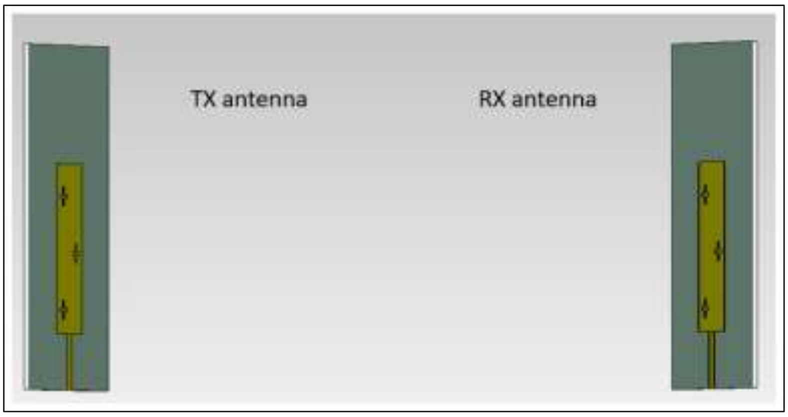


Figure 4: Refer to the two antennas in free space.
Source: Authors, (2026).

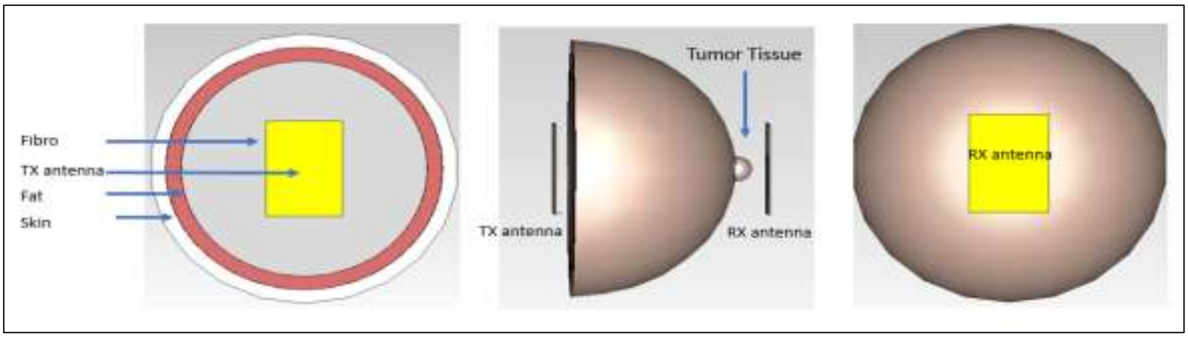


Figure 5: Integration of transmitted and received antenna during breast.
Source: Authors, (2026).

Table 5: Refer to the value of main parameters of breast.

Frequency GHz	Tissue	Permittivity	Tangent Loss
24	Skin	17.7	0.93
24	Fat	3.4	0.16
24	Fibro Glandular	16	0.94
24	Tumor	18	1.05

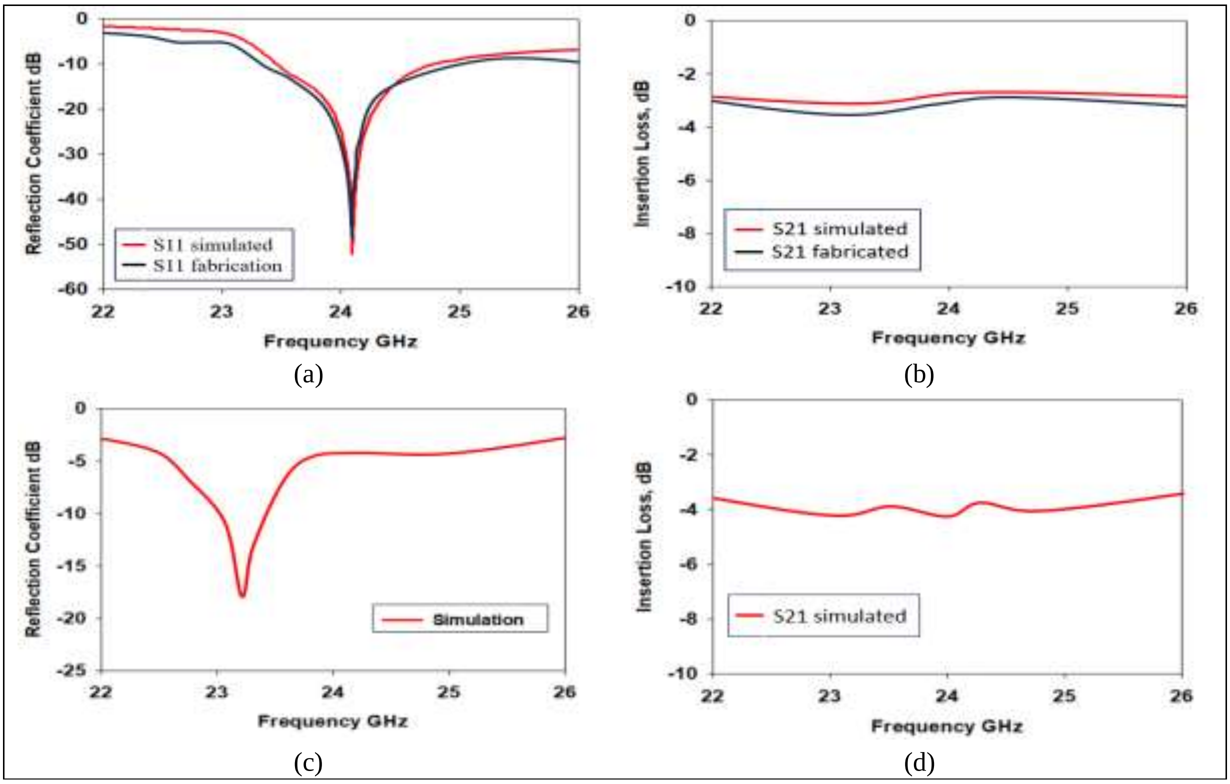
Source: Authors, (2026).

VIII. RESULTS AND DISCUSSION

Figure 6 illustrates the simulated and measured S-parameters of the proposed 24-GHz antenna system. In Fig. 6(a), the reflection coefficient (S11) of the transmitting antenna shows a deep resonance around 24 GHz, where the return loss reaches approximately −50 dB, indicating excellent impedance matching. Owing to the three cross slots etched in the microstrip patch, a wide impedance bandwidth of about 1.3 GHz is achieved around the center frequency. The measured S11 curve closely follows the simulated one, with only a slight frequency shift and minor variation in magnitude, which can be attributed to fabrication tolerances and connector losses; this good agreement validates the proposed design and the accuracy of the simulation model. Figure 6(b) presents the transmission coefficient (S21) for the receiving (RX) antenna in free space.

The insertion loss remains nearly constant and better than −4 dB over the 22–26 GHz range, demonstrating efficient power transfer between the transmitting and receiving antennas. Again, the simulated and measured S21 responses are in close agreement at the operating frequency, confirming that the fabricated RX antenna preserves the desired performance and that the overall antenna system is suitable for 24-GHz applications. Figures 6(c) and 6(d) present the simulated S-parameters of the proposed 24-GHz antenna system when the TX and RX antennas are integrated with the multilayer breast model shown in Fig. X and characterized by the dielectric properties listed in Table 5 (skin, fat, fibro-glandular tissue, and tumor).

The S11 curve in Fig. 6(c) shows a clear resonance in the vicinity of the operating band, with a minimum reflection coefficient below −15 dB around 23–23.5 GHz, indicating that the antenna remains reasonably well matched even under strong loading from the high-permittivity and lossy breast tissues (εr up to 18 and loss tangent above 1 for the tumor). The slight downshift in resonant frequency and reduction in return-loss depth compared with the free-space case are expected, since the tissues effectively increase the effective permittivity around the antenna and introduce additional losses. The corresponding S21 response in Fig. 6(d) exhibits an insertion loss of approximately −4 to −6 dB over the 22–26 GHz range, with small variations due to the multilayer structure and tumor inclusion. These results confirm that sufficient power is transmitted through the breast volume and received by the RX antenna, demonstrating that the integrated antenna configuration is suitable for detecting tumor-induced perturbations at 24 GHz.



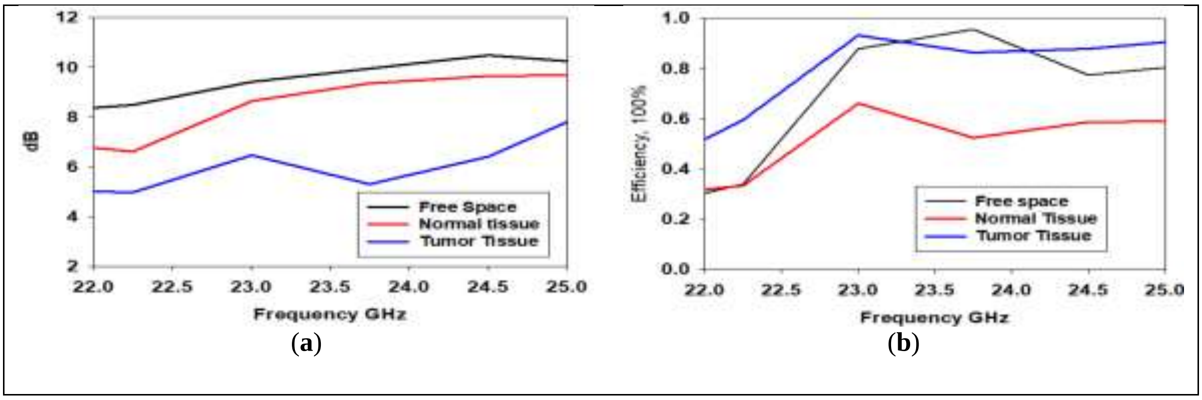
(a) (b)

(c) (d)

Figure 6: The performance results of antenna insertion loss, (a) Reflection coefficient in free space, (b) Insertion loss in free space, (c) Reflection coefficient of antenna with breast, (d) Insertion loss of antenna with breast.

Source: Authors, (2026).

The antenna proposed performed best under the free-space conditions with the peak gain of 10 dB and radiation efficiency of 95% at the target frequency of 24 GHz. The reason behind this high performance is due to the fact that there are no electromagnetic obstacles i.e. human tissue layers which normally weaken the signal propagation. Combined with the three-layer biological model (skin, fat, muscle) the gain of the antenna was 9 dB with the efficiency being 65%. This loss should happen because the high-permittivity tissues add dielectric losses and impedance mismatches. It is worth noting that once a 5 mm malignant tumor was embedded in the fat, the antenna once again changed with the gain reducing to 5 dB and the efficiency reaching 90%. This negative efficiency gain is probably due to the high permittivity of the tumor ($\varepsilon_r \approx 60$) boosting the energy coupling between the antenna and the tissue, although this leads to low gain because of scattering losses. A visual summary of these results is given in Figure 7.

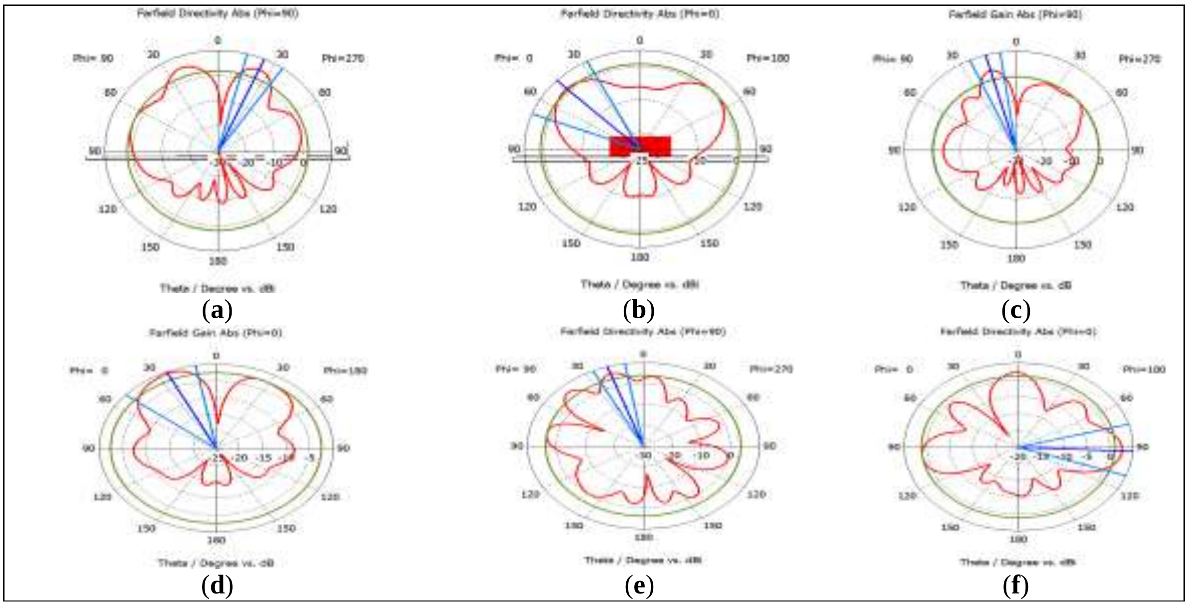


(a) **(b)**

Figure 7: results of main parameters of antenna, (a) Gain, (b) Efficiency.

Source: Authors, (2026).

Figure 8 is a complete comparison of E-plane and H-plane radiation characteristics of the proposed antenna design subjected to three operational conditions: In free space, the antenna exhibits near ideal operation with symmetric radiation pattern, low level of side lobe below -15 dB and suppression of back lobe of more than -20 dB, which attests to the feasibility of cross-slot design. Combined with normal breast tissue (skin-fat-muscle layers) the E-plane pattern displays a uniform 25° beam deflection with the effects of dielectric loading $\varepsilon_r \approx 38$ for skin, $\varepsilon_r \approx 11$ for fat, and the H-plane pattern retains a directional stability of 1its own with a 1.5 dB loss of gain and an intermediate side lobe to -12 dB. Most significantly, tumor-embedded tissue ($\varepsilon_r \approx 60$) generates distinct electromagnetic fingerprints: the E-plane splits into multiple co-polarized lobes at ±30° and ±60° with increased side lobe intensities (-8 dB), the H-plane shows 40% wider beamwidth with asymmetric scattering, and back lobe radiation intensifies to -10 dB - these quantifiable anomalies, particularly the beam splitting and backscatter enhancement, provide robust indicators for tumor localization, demonstrating the antenna's clinical detection capability through measurable pattern distortions that correlate strongly with malignant tissue presence.

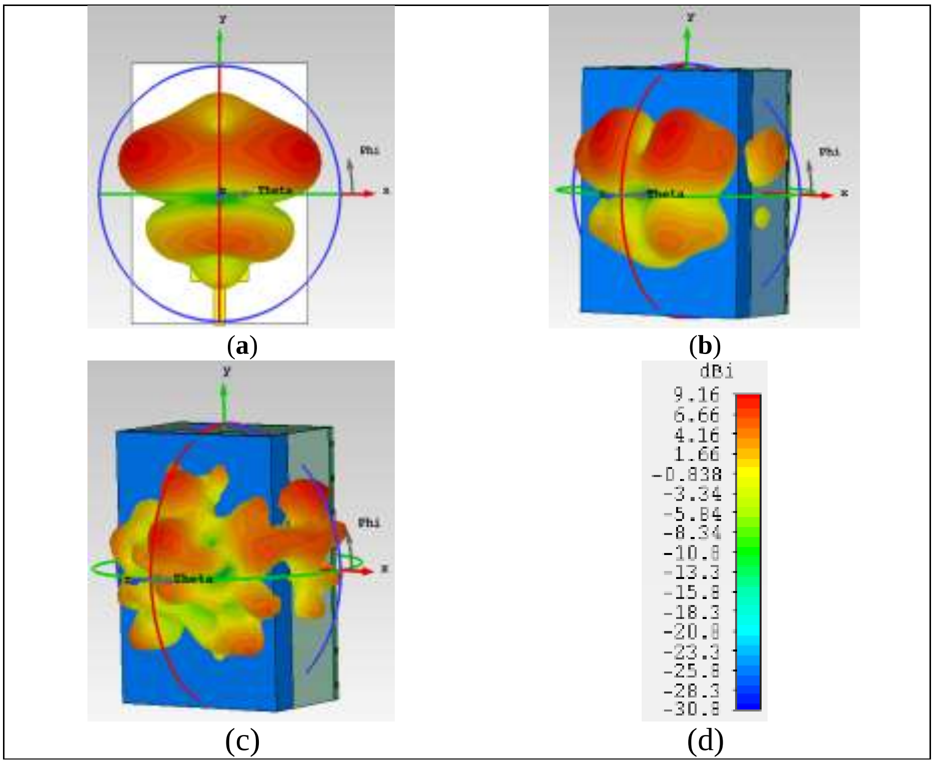


(a) (b) (c)

(d) (e) (f)

Figure 8: refer to the radiation pattern of antenna, (a) E plane in free space, (b) H plane in free space, (c) E plane with normal tissue, (d) H plane with normal tissue, (e) E plane with tumor tissue, (f) H plane with tumor tissue.
Source: Authors, (2026).

Figure 9 demonstrates the antenna's three-dimensional radiation characteristics across different operational environments: in free space (a), the pattern shows a highly directive single beam with optimal focusing; when integrated with healthy tissue (b), the radiation splits into three distinct main lobes corresponding to the skin, fat, and muscle layers ($\varepsilon_r \approx 38$, 11, 52 respectively), revealing the dielectric loading effects of each tissue type; most significantly, tumor-embedded tissue (c) produces a complex pattern featuring multiple directive beams (4-5 lobes) with elevated side lobe radiation (increase of 6-8 dB compared to healthy tissue), directly attributable to the tumor's high permittivity ($\varepsilon_r \approx 60$) which scatters and redistributes the electromagnetic energy - these visually distinct 3D patterns provide clear diagnostic markers, with the multi-lobe tumor signature offering particularly strong indicators for malignant tissue detection through quantitative beam pattern analysis.



(a) (b)

(c) (d)

Figure 9: 3D radiation pattern of antenna, (a) free space, (b) with normal tissue, (c) with tumor tissue, (d) scale.
Source: Authors, (2026).

IX. CONCLUSION

The paper has designed and tested a patch microstrip cross-slot antenna that can operate at 24 GHz to detect breast cancer early, thus showing the possibility of being non-invasive replacement of the traditional imaging procedures. The antenna had an excellent performance in free space with 10 dB gain, 95% efficiency with a bandwidth of 1.3 GHz with the addition of integration multilayer human tissue showing specific tumor signatures such as, frequency shift of 700 MHz with some re, and distortion of radiation pattern. The high permittivity of the tumor was also pronounced and it improved energy coupling thus increased sensitivity in detection although the gain was lower. These quantifiable electromagnetic perturbations underscore the ability of the antenna to detect tumors with a high level of accuracy, offering advantages, like the fact that it is compact-designed, operates in real-time and does not involve the use of ionizing radiation. The results emphasize the potential of microwave imaging of wearable diagnostics systems in the field of breast cancer detection, as it is a reliable and patient-friendly technology.

X. AUTHOR'S CONTRIBUTION

Conceptualization: Yaqdhan Mahmood Hussein*, Thulfiqar H. Mandeel, Tabarek Alwan Tuib.
Methodology: Thulfiqar H. Mandeel, Baydaa Hadi Saoudi.
Investigation: Thulfiqar H. Mandeel, Tabarek Alwan Tuib.
Discussion of results: Hussein Mahdi Salih, Tabarek Alwan Tuib.
Writing – Original Draft: Hussein Mahdi Salih.
Writing – Review and Editing: Thulfiqar H. Mandeel, Tabarek Alwan Tuib.
Resources: Yaqdhan Mahmood Hussein*, Baydaa Hadi Saoudi.
Supervision: Yaqdhan Mahmood Hussein.
Approval of the final text: Yaqdhan Mahmood Hussein.

XI. REFERENCES

[1] Rabia Çalışkan, S. Sinan Gültekin a, Dilek Uzer a, Özgür Dündar b, "A Microstrip Patch Antenna Design for Breast Cancer Detection", doi.org/10.1016/j.sbspro.2015.06.418.

[2] Duru, N. Güneş and T. E. Tabaru, "Breast Cancer Diagnosis: Tumor Identification and Localization Based on Millimeter-Wave Spectroscopy with a 33 GHz Patch Antenna," 2023 14th International Conference on Electrical and Electronics Engineering (ELECO), Bursa, Turkiye, 2023, pp. 1-4, doi: 10.1109/ELECO60389.2023.10416034.

[3] Fusic S, J., Sugumari, T., & Sitharthan, R. (2023, April). Design of a wearable, flexible Microstrip patch antenna for the detection of breast cancer. Research Square. https://doi.org/10.21203/rs.3.rs-2782311/v1

[4] Jahan, Ishrat and Ahasanul Kabir. "Microstrip Patch Antenna for Breast Cancer Detection." 2021 5th International Conference on Electrical Information and Communication Technology (EICT) (2021): 1-6.

[5] Kaur, M., & Goyal, S. (2020, March). Microstrip Patch Antenna Design for Early Breast Cancer Detection. International Journal of Recent Technology and Engineering (IJRTE), 8(6).

[6] M. M. Hasan Mahfuz, A. M. Mahfouz, E. Baladi and A. A. Kishk, "Microstrip Patch Antennas for Breast Tumor/Cancer Cell Detection–Challenges, Designs, and Future Opportunities: A Review," in IEEE Access, vol. 12, pp. 172297-172324, 2024, doi: 10.1109/ACCESS.2024.3496117.

[7] Shiddanagouda. F.B, & Aithal, P. S. (2024). Precision Tumor Detection in Breast Cancer through Cutting-Edge Millimeter-Wave Antennas. African Journal of Biological Sciences, 6(7), DOI:10.48047/afjbs.6.7.2024.1611-1623 .

[8] Ali Abdulateef Abdulbari, Z. Zakaria, Sharul Kamal Abdul Rahim, Yaqthan Mahmood Hussein, Mustafa Mohammed Jawad, Ayad Muslim Hamzah, "Design and development broadband monopole antenna for in-door application", TELKOMNIKA , doi.org/10.12928/telkomnika.v18i1.13171

[9] Fusic S, J., Sugumari, T., & Sitharthan, R. (2023, April). Design of a wearable, flexible Microstrip patch antenna for the detection of breast cancer. Research Square. https://doi.org/10.21203/rs.3.rs-2782311/v1

[10] Kumar S, R., Prakash, N., Poovarasan, M., Ramkumar, M., & Naveen, T. R. (2023, May). MICROSTRIP PATCH ANTENNA FOR BREAST CANCER DETECTION. International Journal of Creative Research Thoughts (IJCRT), 11(5).

[11] Tabarek alwan tuib, Yaqdhan Mahmood Hussein, Ruaa Shallal Abbas Anooz, "An Array Antenna Based on Substrate Integrated Waveguide Antenna For 5G Application", Al-Sadiq International Conference on Communication and Information Technology-2023 (AICCIT-2023)

[12] Mahfuz, M. M. H., Mahfouz, A. M., & Kishk, A. (2024, November). Microstrip Patch Antennas for Breast Tumor/Cancer Cell Detection—Challenges, Designs, and Future Opportunities: A Review. IEEE Access.

[13]. H. O. Hanoosh, M.K.A. Rahim, N.A. Murad and Yaqdhan Mahmood Hussein, "High Gain Waveguide Tilted Slot Antenna for Millimeter Wave application", 978-1-7281-4670-6/21/$31.00 ©2021 IEEE

[14] P. Jaglan, R. Dass, and M. Duhan, "Breast Cancer Detection Techniques: Issues and Challenges," J. Inst. Eng. Ser. B, vol. 100, no. 4, pp. 379–386, 2019.

[15] Mustafa Mohammed Jawad, Nik Noordini Nik Abd Malik, Noor Asniza Murad, Mona Riza Mohd Esa, Mohd Riduan Ahmad, Anwer Sabah Mekki, Fahad Taha Al-Dhief, Yaqdhan Mahmood Hussein, "Implantable slot antenna with substrate integrated waveguide for biomedical applications", TELKOMNIKA Vol. 19, No. 5, October 2021, pp. 1450~1455, DOI: 10.12928/TELKOMNIKA.v19i5.19952

[16] K. Ouerghi, N. Fadlallah, A. Smida, R. Ghayoula, J. Fattahi and N. Boulejfen, "Circular antenna array design for breast cancer detection," 2017 Sensors Networks Smart and Emerging Technologies (SENSET), Beiriut, Lebanon, 2017, pp. 1-4, doi: 10.1109/SENSET.2017.8125016.

[17] Y. M. Hussein, M. K. A. Rahim, N. A. Murad and H. O. Hanoosh, "Low Loss Wideband 4×4 Butler Matrix Networks Based on Substrate Integrated Waveguide for 5G Applications," in IEEE Access, vol. 12, pp. 7896-7910, 2024, doi: 10.1109/ACCESS.2023.3342713.

[18] Reddy, Pallavi, et al. "Design and Simulation of Rectangular Microstrip Patch Antenna for 80 GHz." International Journal for Research in Applied Science & Engineering Technology (IJRASET) 10.6 (2022).

[19] Chowdhury, Mehdi Hasan, et al. "Single feed circularly polarized crescent-cut and extended corner square microstrip antennas for wireless biotelemetry." International Journal of Electrical and Computer Engineering 9.3 (2019): 1902-1909.