Design and experimental validation of a microstrip Vivaldi antenna-based system for breast tumor detection

Samiya Qanoune, Hassan Ammor, Zakaria Er-Reguig, Zouhair Guennoun
ERSC Team, Mohammadia Engineering School, Mohammed V University, Rabat, Morocco

Article Info

Article history:

Received May 10, 2025
Revised Jul 21, 2025
Accepted Sep 16, 2025

Keywords:

Breast cancer
Microwave imaging
Ultra-wideband
Vivaldi antenna

ABSTRACT

Breast cancer remains one of the leading causes of death among women worldwide, highlighting the critical need for accurate, non-invasive, and cost-effective diagnostic solutions. In light of this, microwave imaging has surfaced as a promising alternative to conventional diagnostic methods. This approach leverages its capability to differentiate between healthy and cancerous tissues by examining their dielectric properties. This study presents the design, implementation, and experimental assessment of a Vivaldi antenna-based system aimed at breast cancer detection. The antenna is designed to operate within the ultra-wideband frequency range, which facilitates high-resolution imaging and effective deep tissue penetration. Data collected from tissue-mimicking phantoms reveals the system's proficiency in identifying anomalies, showcasing a significant contrast between malignant and normal tissue regions. We analyze various performance metrics, including signal reflection, penetration depth, and imaging resolution to substantiate the system's efficacy. The results underline the significant potential of Vivaldi antennas in improving early-stage breast cancer detection, thus contributing to advancements in microwave imaging technology.

Corresponding Author:

Samiya Qanoune
ERSC Team, Mohammadia Engineering School, Mohammed V University
Rabat, Morocco
Email: samiyaqan@gmail.com

1. INTRODUCTION

Breast cancer is the most common cancer among women and one of the leading causes of cancer-related deaths worldwide. According to World Health Organization reports, in 2022 there were approximately 2.3 million new cases of breast cancer, resulting in nearly 670,000 deaths [1]. In the United States alone, it is estimated that there will be more than 316,000 new cases and over 42,000 deaths in 2025 [2]. The cumulative risk of developing breast cancer in women is estimated to be approximately 13%, or one in eight women [3]. Early detection of the disease has a significant impact on improving survival rates, with five-year survival rates exceeding 90% when diagnosed in the early stages [1]. These data underscore the urgent need to develop advanced diagnostic technologies that are accurate and reliable, as well as non-invasive and accessible, in order to enhance the chances of early diagnosis.

Although traditional imaging modalities such as mammography, ultrasound, and magnetic resonance imaging (MRI) are widely used in clinical practice, they have several limitations. For example, mammography has a limited efficacy in women with dense tissue and it exposes patients to ionizing radiation. While ultrasound is highly reliant on operator expertise and remains limited in terms of image resolution. MRI, although his high sensitivity, but still expensive and time-consuming [4]. Given these limitations, in recent years, researchers started to focus on developing alternative technologies that can be safe, low-cost, and capable of detecting tumors in their early stages.

Microwave imaging is emerging as a promising approach, exploiting the prominent dielectric contrast between healthy and malignant breast tissues at microwave frequencies. This technique provides non-ionizing, non-invasive imaging and it has demonstrated significant potential for breast cancer detection [5]. Among the broadband antennas used in biomedical applications, the Vivaldi antenna stands out for its excellent wideband (UWB) performance and high gain, as well as its directional radiation, compact flat design, and low manufacturing cost.

Recent research has focused on developing and designing improved Vivaldi antennas with the aim of improving breast imaging using microwaves. These efforts have included expanding the bandwidth of the antennas, increasing their efficiency, and integrating them with breast tissue simulators to evaluate their ability to detect tumors [6]–[10]. Recent studies suggest that the use of super materials in Vivaldi antenna arrays can significantly enhance imaging accuracy and sensitivity [11]. These developments reflect the fundamental role that Vivaldi antennas can play in the design of practical and effective systems for the early detection of breast cancer using microwaves [12].

In this work, we present the design, simulation, and experimental validation of a microstrip Vivaldi antenna-based system intended for early breast tumor detection. The antenna is designed to operate across a wide frequency range suitable for high-resolution imaging and effective tissue penetration. The system is modular, low-cost, and incorporates a custom antenna support structure and data acquisition platform to enable accurate dielectric anomaly detection in breast-mimicking phantoms. This study's novelty resides in the practical integration and experimental verification of a compact UWB Vivaldi antenna within a breast cancer detection system, emphasizing reproducibility, modularity, and applicability in real-world settings. Unlike prior works focused mainly on simulation or limited experimental setups [6]–[12], our approach seeks to bridge the gap toward clinically viable microwave imaging solutions aimed at improving early breast cancer detection accessibility and affordability.

The remainder of this article is organized as follows: section 2 details the design and fabrication of the breast-mimicking phantom models used to replicate realistic tissue dielectric properties. Section 3 describes the design methodology and simulation results of the proposed Vivaldi antenna, including its optimized parameters. Section 4 presents the system prototype architecture, including the antenna support structure and data acquisition components. Finally, section 5 discusses the experimental validation approach and summarizes the key findings, while Section 6 concludes the paper and outlines future research directions.

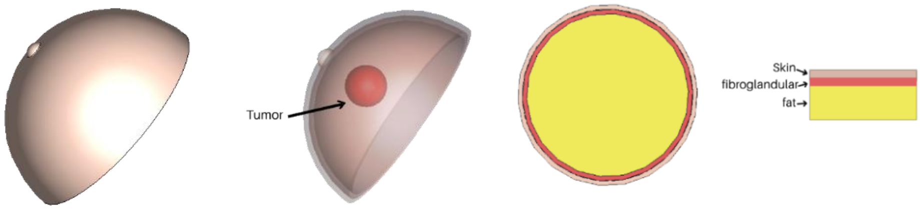
2. BREAST MODEL

To replicate realistic conditions for microwave imaging experiments, two multi-layer breast phantoms were developed specifically for this study. Each phantom comprises three main layers: skin, fibroglandular tissue, and adipose tissue, carefully engineered to mimic the anatomical and dielectric properties of human breast tissue [13]. The skin layer is modeled as a thin, uniform outer shell, while the interior contains heterogeneous fibroglandular tissue enveloped by fatty tissue, reproducing a realistic electromagnetic scattering environment [14]. One phantom represents a healthy breast without abnormalities, and the other includes a spherical, high-contrast inclusion designed to simulate a tumor [15]. This dual-phantom approach enables direct comparison between healthy and tumorous tissue responses during imaging. The dielectric properties for each component and tumor inclusion were assigned based on values reported in prior experimental studies to ensure accurate biological representation [16]. These phantoms provide a reliable and repeatable test environment to validate the detection capabilities of the Vivaldi antenna-based system [17].

As shown in Figure 1, the multi-layer breast phantom models include the healthy phantom without a tumor in Figure 1(a), the phantom with a tumor inclusion in Figure 1(b), and a detailed depiction of the breast's layered anatomy in Figure 1(c). Figure 2 presents actual photographs of the fabricated breast phantoms from our laboratory: Figure 2(a) shows the tumor-containing breast model, and Figure 2(b) shows the healthy breast model. These images demonstrate the physical realization of the phantoms used in the experimental setup [18].

3. ANTENNA DESIGN

The Vivaldi antenna is a tapered slot antenna structure renowned for its ultra-wideband (UWB) behavior, low dispersion, and high gain properties that make it a promising candidate for biomedical imaging, particularly for microwave-based breast cancer detection [19], [20]. Its exponentially flared shape facilitates efficient radiation over a broad frequency spectrum, enabling high spatial resolution and deep tissue penetration both essential for distinguishing malignant from normal breast tissues.



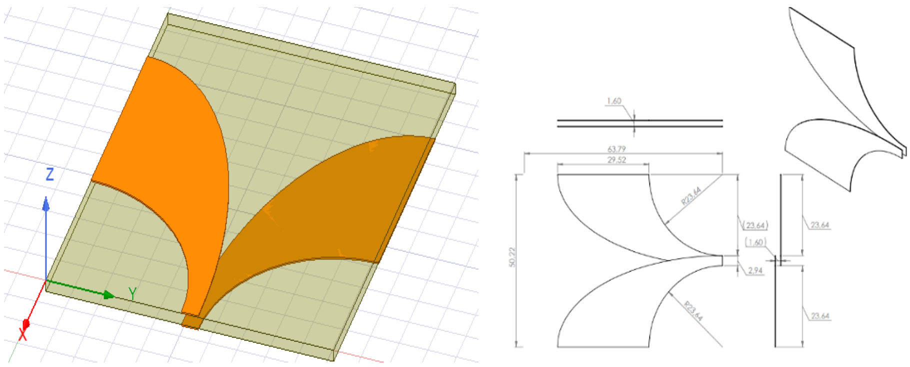
(a) (b) (c)

Figure 1. Multi-layer breast phantom models (a) without tumor, (b) with tumor, and (c) detailed layers of the breast

Figure 2. Realistic breast models for microwave imaging (developed in our laboratory) (a) breast with tumor and (b) healthy breast

In this study, we developed a compact antipodal Vivaldi antenna designed to operate between 3 and 10 GHz. The antenna comprises two metallic arms that flare exponentially from a narrow slot line fed through a microstrip transition. This geometry ensures excellent impedance matching and stable directional radiation over the entire frequency band [21]. The choice of substrate material, taper rate, and arm spacing was optimized to balance bandwidth, gain, and physical compactness. A ground plane with an extended flare was added to suppress back-lobe radiation, ensuring forward-directed wave propagation a desirable characteristic for near-field microwave imaging [22].

The fabricated prototype, as illustrated in Figure 3(a), shows the detailed layout of the proposed Vivaldi antenna, while Figure 3(b) provides its physical dimensions. The final design was realized using standard PCB manufacturing techniques, making the solution cost-effective and easily reproducible. A photograph of the fabricated antenna is shown in Figure 4. Preliminary free-space tests confirmed stable radiation patterns, smooth return loss behavior, and wide impedance bandwidth, reinforcing the antenna's suitability for detecting dielectric anomalies in breast phantoms.



(a) (b)

Figure 3. Illustration of the proposed (a) antipodal Vivaldi antenna and (b) its dimension in mm

Compared to traditional narrowband antennas, the Vivaldi structure provides better axial resolution and lower sidelobes, which are beneficial for reconstructing accurate dielectric profiles in imaging systems. Furthermore, its planar design and lightweight profile enable easy integration into rotating or fixed imaging setups [23]. The developed antenna thus offers a viable solution for low-cost, contactless breast cancer screening systems, especially in point-of-care or low-resource clinical environments [24].

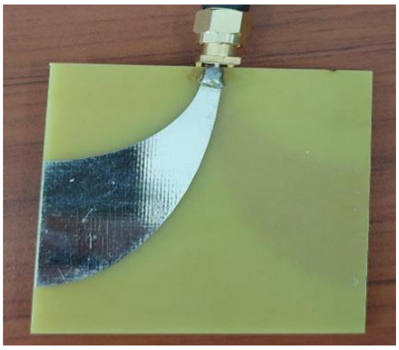


Figure 4. Top-view image of the designed Vivaldi antenna

4. SYSTEM PROTOTYPE AND IMPLEMENTATION

The developed microwave imaging system is centered around a radiofrequency (RF) platform designed to facilitate non-invasive breast cancer detection by exploiting the dielectric contrast between healthy and malignant tissues. At its core, the system features 24 ultra-wideband (UWB) Vivaldi-type microstrip antennas arranged cylindrically around a breast phantom. These antennas are selected for their high gain, directional radiation, and broad bandwidth, all of which are essential for accurate microwave imaging [25]. The antenna array operates in a semi-multi-static configuration. At each step of the scanning process, one antenna acts as the transmitter while two adjacent antennas function as receivers. This localized triad setup enhances signal capture while reducing hardware complexity and interference. Once data is acquired at the current position, the system advances to the next configuration, repeating the process until all angular positions around the phantom have been scanned. This method ensures complete spatial coverage while keeping the acquisition process efficient and synchronized [26].

To enable vertical scanning and 3D imaging, the array is mounted on a high-precision linear actuator that adjusts the height of the antenna set. This feature allows the system to acquire data across multiple horizontal slices of the phantom, forming a volumetric dataset of the breast tissue structure [27].
The support structure for the antenna array was carefully designed and modeled using 3D CAD software to ensure precise alignment, mechanical stability, and minimal electromagnetic interference. As shown in Figure 5, the model provides a top-down and side-view layout of the antenna positions, while Figure 6 displays its physical dimensions. The fabricated prototype, presented in Figure 7, reflects a compact and modular design aimed at ease of assembly and portability.

A key strength of this system lies in its contactless nature, which eliminates the need for physical compression, enhancing patient comfort and removing potential signal distortion from tissue deformation. Furthermore, its modular design allows for future upgrades such as improved control logic, image reconstruction algorithms, or wireless data acquisition interfaces [28]. Overall, this implementation demonstrates the feasibility of a low-cost, flexible, and scalable platform for microwave breast cancer screening in experimental conditions. Its practicality and reproducibility make it well-suited for further clinical research and adaptation in resource-limited environments [29].

5. RESULTS AND DISCUSSION

The initial experimental results as shown in Figure 8, demonstrate the efficacy of the proposed Vivaldi antenna system in detecting breast tissue anomalies through microwave imaging. The antenna exhibits stable and directional radiation patterns across the 3.5 to 4.5 GHz frequency range as shown in Figure 9, which is crucial for high-resolution imaging and precise tumor localization [26], [27]. The effect of antenna spacing was investigated by evaluating the S11 parameter for different distances between the three vertical antenna row. As shown in Figure 10, minimizing the reflection losses through optimal spacing significantly enhances system sensitivity and signal quality [28].

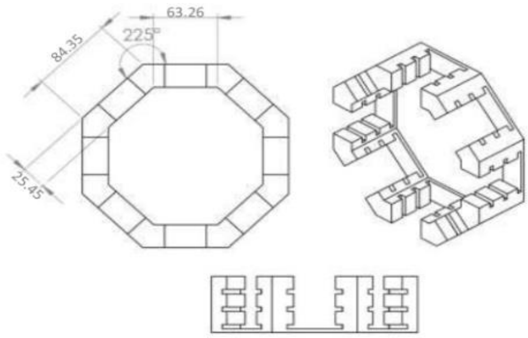


Figure 5. Dimensions of the antenna support structure in millimeters (mm)

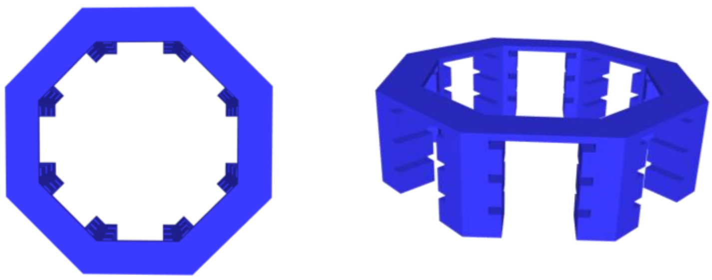


Figure 6. 3D model of the support and its dimensions in mm

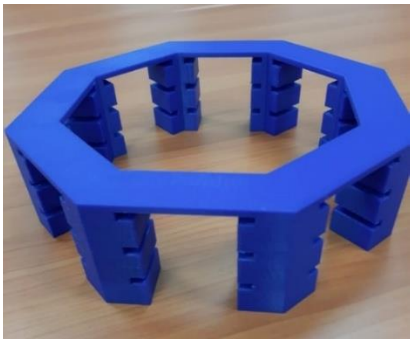


Figure 7. Photograph of the fabricated support structure

Figure 8. Image of the experimental setup, including the Vivaldi antennas and the breast-mimicking phantom

This first phase of experimentation was conducted in a controlled laboratory setup using multilayered breast phantoms designed to mimic human tissue properties. Although realistic, these phantoms do not fully replicate the heterogeneity and anatomical complexity of actual breast tissue. Additionally, factors such as environmental noise, variations in dielectric properties, and antenna mutual coupling were not yet analyzed and are left for future investigation.

Compared to prior microwave imaging systems reported in the literature [29]–[34], the proposed system introduces a multi-static antenna array configuration combined with vertical scanning capabilities, allowing for detailed volumetric imaging with improved spatial resolution. A summary comparison is provided in Table 1, highlighting the enhancements in design and functionality over similar systems. These findings validate the potential of the system as a promising tool for non-invasive breast cancer detection, laying the foundation for further development toward clinical applicability.

Table 1 presents a comparative overview of recent microwave imaging systems and highlights the distinguishing features of our proposed approach. Many earlier studies have employed fewer antennas [29], lacked vertical scanning mechanisms [30], or relied on single-static configurations that limit imaging depth and resolution [31]. In contrast, our system integrates a 24-element Vivaldi antenna array arranged in a multi-static configuration with precise vertical scanning capability, enabling high-resolution volumetric imaging. Furthermore, while some prior systems used complex and costly materials or lacked mechanical adaptability [32], the inclusion of a 3D-printed support in our setup ensures structural accuracy, repeatability, and cost-effectiveness. The combination of optimized antenna placement, wide bandwidth coverage, and modular mechanical design demonstrates a practical advancement over existing models [33], [34]. These comparisons underline the novelty of our system and its strong potential for reliable, scalable, and patient-friendly breast cancer screening [35].

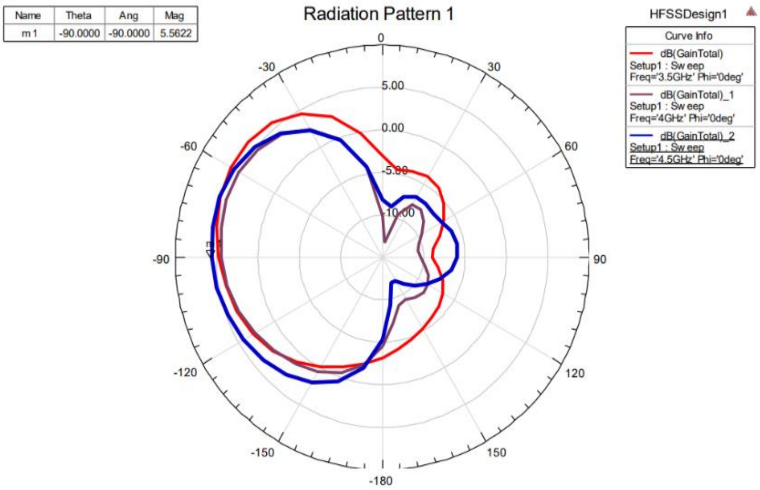


Figure 9. Radiation patterns of the Vivaldi antenna at three frequencies: 3.5, 4, and 4.5 GHz

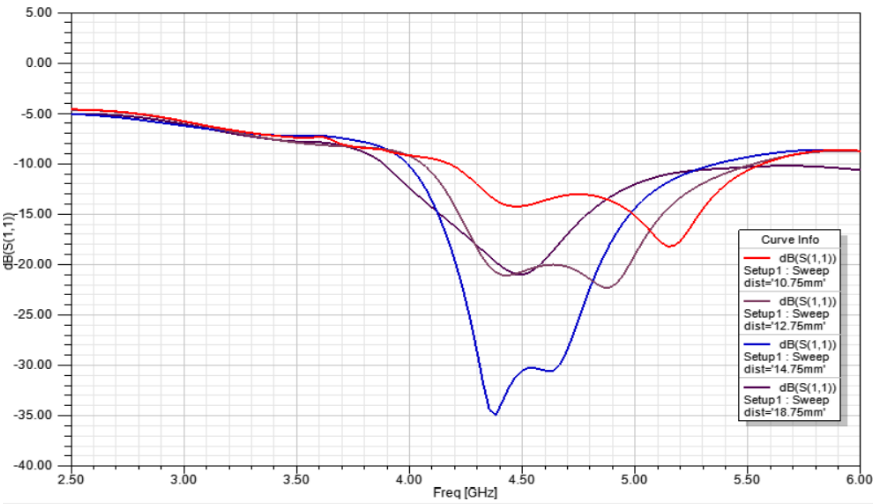


Figure 10. S11 parameter of the Vivaldi antennas for different distances between the three vertical rows

Future work will focus on enhancing the system by integrating microwave switches to automate antenna selection and streamline the data acquisition process, thereby improving measurement speed and repeatability. Additionally, efforts will be directed toward developing advanced image reconstruction algorithms to improve tumor detection accuracy and spatial resolution. Expanding experimental validation using more realistic breast phantoms and eventually clinical trials will further demonstrate the system’s practical applicability and robustness. This phase will also investigate mitigating interference and environmental noise to optimize performance in real-world conditions.

Table 1. Comparative table of breast cancer detection systems

Feature	This work	Sharma *et al.* [27]	Hammouch *et al.* [28]	Jamlos *et al.* [29]	Kumari *et al.* [30]
Number of antennas	24	16	12	8	10
Frequency range (GHz)	3.5 – 4.5	3.1 – 10	2.5 – 5	3 – 5	3.5 – 6
Multi-static configuration	Yes	Yes	Yes	No	Yes
Vertical scanning	Yes (linear actuator)	No	No	No	No
Breast phantom type	Multi-layer (tumor and healthy)	Simplified	Multi-layer	Simplified	Multi-layer
Non-contact detection	Yes	Yes	Yes	Yes	Yes
Clinical validation stage	Phase 1 (phantom experiments)	Simulation only	Simulation + phantom	Prototype	Prototype

6. CONCLUSION

This study presents the design and experimental validation of a novel breast cancer detection system based on a multi-static Vivaldi antenna array with vertical scanning capability. The initial experimental results demonstrated the system's ability to detect dielectric contrasts in multi-layer breast phantoms, validating its potential for non-invasive and contactless breast tumor detection. The antenna's stable radiation patterns and optimized array configuration contribute to high-resolution imaging performance. Although this work represents the first phase of validation under controlled laboratory conditions, it lays a solid foundation for further development. Future efforts will focus on system automation through microwave switches, advanced image reconstruction, and comprehensive testing with realistic phantoms and clinical environments. These advancements will be essential for translating the system into a practical diagnostic tool, improving early breast cancer detection and patient outcomes.

FUNDING INFORMATION

Authors state no funding involved.

AUTHOR CONTRIBUTIONS STATEMENT

This journal uses the Contributor Roles Taxonomy (CRediT) to recognize individual author contributions, reduce authorship disputes, and facilitate collaboration.

Name of Author	C	M	So	Va	Fo	I	R	D	O	E	Vi	Su	P	Fu
Samiya Qanoune	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓			
Hassan Ammor	✓	✓		✓		✓	✓			✓		✓	✓	✓
Zakaria Er-Reguig	✓	✓	✓	✓		✓	✓			✓				
Zouhair Guennoun										✓		✓		

C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
Fo : **Fo**rmal analysis
I : **I**nvestigation
R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

CONFLICT OF INTEREST STATEMENT

Authors state no conflict of interest.

DATA AVAILABILITY

The authors confirm that the data supporting the findings of this study are available within the article and its supplementary materials.

REFERENCES

[1] WHO, "Breast cancer," *World Health Organization*, 2022. https://www.who.int/news-room/fact-sheets/detail/breast-cancer (accessed May 10, 2025).
[2] American Cancer Society, "Breast cancer facts & figures 2023–2025," *American Cancer Society*, 2023, Accessed: May 10, 2025. [Online]. Available: https://www.cancer.org/content/dam/cancer-org/research/cancer-facts-and-statistics/breast-cancer-facts-and-figures/2024/breast-cancer-facts-and-figures-2024.pdf

[3] NCI, “Breast cancer risk in American women,” *National Cancer Institute*, 2023. https://www.cancer.gov/types/breast/risk-fact-sheet (accessed May 10, 2025).

[4] D. Sathish, S. Kamath, K. V. Rajagopal, and K. Prasad, “Medical imaging techniques and computer aided diagnostic approaches for the detection of breast cancer with an emphasis on thermography - a review,” *International Journal of Medical Engineering and Informatics*, vol. 8, no. 3, p. 275, 2016, doi: 10.1504/IJMEI.2016.077446.

[5] L. Wang, “Microwave imaging and sensing techniques for breast cancer detection,” *Micromachines*, vol. 14, no. 7, p. 1462, Jul. 2023, doi: 10.3390/mi14071462.

[6] M. Samsuzzaman, M. T. Islam, M. T. Islam, A. A. S. Shovon, R. I. Faruque, and N. Misran, “A 16-modified antipodal Vivaldi antenna array for microwave-based breast tumor imaging applications,” *Microwave and Optical Technology Letters*, vol. 61, no. 9, pp. 2110–2118, Sep. 2019, doi: 10.1002/mop.31873.

[7] H. M. El Misilmani, T. Naous, S. K. Al Khatib, and K. Y. Kabalan, “A survey on antenna designs for breast cancer detection using microwave imaging,” *IEEE Access*, vol. 8, pp. 102570–102594, 2020, doi: 10.1109/ACCESS.2020.2999053.

[8] M. T. Islam, M. T. Islam, M. Samsuzzaman, H. Arshad, and H. Rmili, “Metamaterial loaded nine high gain Vivaldi antennas array for microwave breast imaging application,” *IEEE Access*, vol. 8, pp. 227678–227689, 2020, doi: 10.1109/ACCESS.2020.3045458.

[9] V. Kumari, G. Sheoran, and T. Kanumuri, “SAR analysis of directive antenna on anatomically real breast phantoms for microwave holography,” *Microwave and Optical Technology Letters*, vol. 62, no. 1, pp. 466–473, Jan. 2020, doi: 10.1002/mop.32037.

[10] S. Saleh, T. Saeidi, and N. Timmons, “Simple compact UWB Vivaldi antenna arrays for breast cancer detection,” *Telecom*, vol. 5, no. 2, pp. 312–332, Apr. 2024, doi: 10.3390/telecom5020016.

[11] F. Zerrad *et al.*, “Microwave imaging approach for breast cancer detection using a tapered slot antenna loaded with parasitic components,” *Materials*, vol. 16, no. 4, p. 1496, Feb. 2023, doi: 10.3390/ma16041496.

[12] M. Slimi, B. Jmai, H. Dinis, A. Gharsallah, and P. M. Mendes, “Metamaterial Vivaldi antenna array for breast cancer detection,” *Sensors*, vol. 22, no. 10, p. 3945, May 2022, doi: 10.3390/s22103945.

[13] S. Di Meo *et al.*, “Development of multi-layer tissue-mimicking breast phantoms for microwaves and millimeter-waves imaging,” in *2023 IEEE MTT-S International Microwave Biomedical Conference (IMBioC)*, Sep. 2023, pp. 103–105. doi: 10.1109/IMBioC56839.2023.10305139.

[14] M. V. Polyakov and D. S. Sirotin, “A realistic breast phantom for investigating the features of the microwave radiometry method using mathematical and physical modelling,” *Technologies*, vol. 13, no. 3, p. 106, Mar. 2025, doi: 10.3390/technologies13030106.

[15] S. Poompavai and V. Gowri Sree, “Dielectric property measurement of breast—tumor phantom model under pulsed electric field treatment,” *IEEE Transactions on Radiation and Plasma Medical Sciences*, vol. 2, no. 6, pp. 608–617, Nov. 2018, doi: 10.1109/TRPMS.2018.2868818.

[16] M. Lazebnik, E. L. Madsen, G. R. Frank, and S. C. Hagness, “Tissue-mimicking phantom materials for narrowband and ultrawideband microwave applications,” *Physics in Medicine and Biology*, vol. 50, no. 18, pp. 4245–4258, Sep. 2005, doi: 10.1088/0031-9155/50/18/001.

[17] N. Hammouch and H. Ammor, “An accurate UWB technique for breast cancer detection using microwave specific absorption rate,” *International Journal of Microwave and Optical Technology*, vol. 13, no. 5, pp. 424–431, 2018.

[18] M. T. Islam, M. Samsuzzaman, S. Kibria, and M. T. Islam, “Experimental breast phantoms for estimation of breast tumor using microwave imaging systems,” *IEEE Access*, vol. 6, pp. 78587–78597, 2018, doi: 10.1109/ACCESS.2018.2885087.

[19] M. Z. Mahmud, M. T. Islam, N. Misran, A. F. Almutairi, and M. Cho, “Ultra-wideband antenna sensor-based microwave breast imaging: A review,” *Sensors*, vol. 18, no. 9, p. 2951, Sep. 2018, doi: 10.3390/s18092951.

[20] U. Rafique, S. Pisa, R. Cicchetti, O. Testa, and M. Cavagnaro, “Ultra-wideband antennas for biomedical imaging applications: A survey,” *Sensors*, vol. 22, no. 9, p. 3230, Apr. 2022, doi: 10.3390/s22093230.

[21] S. Guruswamy, R. Chinniah, and K. Thangavelu, “Design and implementation of compact ultra-wideband Vivaldi antenna with directors for microwave-based imaging of breast cancer,” *Analog Integrated Circuits and Signal Processing*, vol. 108, no. 1, pp. 45–57, Jul. 2021, doi: 10.1007/s10470-021-01859-2.

[22] N. M. Borkar and P. K. Parlewar, “Antipodal UWB antenna with directivity for microwave tomography and reconfigurable design for biomedical applications,” *International Journal of Applied Electromagnetics and Mechanics*, vol. 79, no. 1, pp. 48–71, Sep. 2025, doi: 10.1177/13835416251336062.

[23] Ş. Yıldız and M. B. Kurt, “Breast cancer detection using a high-performance ultra-wideband Vivaldi antenna in a radar-based microwave breast cancer imaging technique,” *Applied Sciences*, vol. 15, no. 11, p. 6015, May 2025, doi: 10.3390/app15116015.

[24] A. W. Preece, I. Craddock, M. Shere, L. Jones, and H. L. Winton, “MARIA M4: clinical evaluation of a prototype ultrawideband radar scanner for breast cancer detection,” *Journal of Medical Imaging*, vol. 3, no. 3, p. 033502, Jul. 2016, doi: 10.1117/1.JMI.3.3.033502.

[25] P. Meaney, T. Raynolds, S. Geimer, G. Player, X. Yang, and K. Paulsen, “3D-printed gear system for antenna motion in an MR environment: initial phantom imaging experiments,” in *2022 IEEE International Symposium on Antennas and Propagation and USNC-URSI Radio Science Meeting (AP-S/URSI)*, Jul. 2022, pp. 896–897. doi: 10.1109/AP-S/USNC-URSI47032.2022.9886820.

[26] D. Álvarez Sánchez-Bayuela *et al.*, “A multicentric, single arm, prospective, stratified clinical investigation to confirm MammoWave’s ability in breast lesions detection,” *Diagnostics*, vol. 13, no. 12, p. 2100, Jun. 2023, doi: 10.3390/diagnostics13122100.

[27] M. K. Sharma *et al.*, “Experimental investigation of the breast phantom for tumor detection using ultra-wide band–MIMO antenna sensor (UMAS) probe,” *IEEE Sensors Journal*, vol. 20, no. 12, pp. 6745–6752, Jun. 2020, doi: 10.1109/JSEN.2020.2977147.

[28] N. Hammouch, A. Rghioui, H. Ammor, M. Oubrek, and J. Lloret, “A low-cost UWB microwave imaging system for early-stage breast cancer detection,” *Multimedia Tools and Applications*, vol. 84, no. 17, pp. 17329–17360, Jul. 2024, doi: 10.1007/s11042-024-19761-0.

[29] M. Aminudin Jamlos, N. Amirah Othman, W. Azani Mustafa, M. Faizal Jamlos, and M. Nur Khairul Hafizi Rohani, “Zero-index metamaterial superstrates UWB antenna for microwave imaging detection,” *Computers, Materials & Continua*, vol. 75, no. 1, pp. 277–292, 2023, doi: 10.32604/cmc.2023.032840.

[30] V. Kumari, A. Ahmed, T. Kanumuri, C. Shakher, and G. Sheoran, “Early detection of cancerous tissues in human breast utilizing near field microwave holography,” *International Journal of Imaging Systems and Technology*, vol. 30, no. 2, pp. 391–400, Jun. 2020, doi: 10.1002/ima.22384.

[31] M. Haynes, J. Stang, and M. Moghaddam, “Microwave breast imaging system prototype with integrated numerical characterization,” *International Journal of Biomedical Imaging*, vol. 2012, pp. 1–18, 2012, doi: 10.1155/2012/706365.

[32] D. Bhargava, P. Rattanadecho, and K. Jiamjiroch, “Microwave imaging for breast cancer detection- a comprehensive review,”

Engineered Science, 2024, doi: 10.30919/es1116.
[33] A. de Jesus Aragão, D. Carvalho, B. Sanches, and W. A. M. Van Noije, "Low-cost device for breast cancer screening: A dry setup IR-UWB proposal," *Biomedical Signal Processing and Control*, vol. 79, p. 104078, Jan. 2023, doi: 10.1016/j.bspc.2022.104078.
[34] V. Zhurbenko, T. Rubæk, V. Krozer, and P. Meincke, "Design and realisation of a microwave three-dimensional imaging system with application to breast-cancer detection," *IET Microwaves, Antennas & Propagation*, vol. 4, no. 12, pp. 2200–2211, Dec. 2010, doi: 10.1049/iet-map.2010.0106.
[35] M. N. Hamza, S. Koziel, and A. Pietrenko-Dabrowska, "Design and experimental validation of a metamaterial-based sensor for microwave imaging in breast, lung, and brain cancer detection," *Scientific Reports*, vol. 14, no. 1, p. 16177, Jul. 2024, doi: 10.1038/s41598-024-67103-9.

BIOGRAPHIES OF AUTHORS

Samiya Qanoune completed her master's degree in medical biotechnology with a focus on bioinformatics at the Faculty of Medicine and Pharmacy, Mohammed I University, Rabat, Morocco. She holds a bachelor's degree in computer science from the Faculty of Sciences, Cadi Ayyad University, Safi, Morocco. She is currently a Ph.D. candidate at the Mohammadia School of Engineering (EMI), Rabat, Morocco, where her research is centered on integrating machine learning techniques into microwave imaging systems for breast cancer detection. Her work aims to create non-invasive diagnostic methods that facilitate earlier tumor detection while improving patient comfort. She can be contacted at email: samiyaqanoune@research.emi.ac.ma.

Hassan Ammor is the director of the Technological Innovation Center and a faculty member in the Department of Electrical Engineering at Mohammadia School of Engineering (EMI). He earned his Ph.D. in microwave techniques from Henri Poincaré University of Nancy, France, in 1988, followed by a Ph.D. in applied sciences from Mohammadia School of Engineering in 1996, specializing in electronics technology and communications. Professor Ammor has published over 100 technical papers in international journals and conferences and has delivered numerous invited presentations at global workshops and symposia. He is also the author of the book Techniques for Measuring the Complex Permittivity of Materials (European University Edition, 2019). Between 2005 and 2023, he has been credited with 15 scientific inventions, including the development of an intelligent Moroccan scanner for breast cancer detection using microwave imaging, which has earned international recognition and several gold medals in research and innovation competitions. He can be contacted at email: ammorhas@yahoo.fr.

Zakaria Er-Reguig is a researcher in the field of antennas and propagation, specializing in software-defined radio (SDR) techniques. He obtained his Ph.D. in electronics and telecommunication from the Mohammad V University in Rabat, Mohammadia School of Engineering, in 2022. With a strong academic background and expertise in wireless communication technologies, Zakaria has actively contributed to various research projects and published numerous patents extensively in his areas of specialization. He can be contacted at email: zakaria_erreguig@um5.ac.ma.

Zouhair Guennoun senior member, IEEE, received his engineering degree in electronics and telecommunications from the Electronics and Electrical Montefiore Institute, ULG Liège, Belgium, in 1987. He earned his M.Sc. in communication systems and Ph.D. in electrical engineering from the Mohammadia School of Engineering (EMI), Rabat, Morocco, in 1993 and 1996, respectively. Between 1990 and 1994, he was a visiting researcher at the Centre for Communication Research (CCR), University of Bristol, UK, where he conducted part of his doctoral research under a split Ph.D. program. He began his academic career at EMI in 1988 as an assistant lecturer and has been a professor since 1996. He formerly served as head of the Laboratory for Electronics and Telecommunications (LEC), now the Smart Communications Research Team (ERSC), at EMI. His research interests include digital signal processing, error control coding, speech processing, and image processing. He is a former member of the executive committee of the IEEE Morocco Section and continues to contribute actively to the advancement of communication technologies in both academic and applied contexts. He can be contacted at email: zouhair@emi.ac.ma.