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A Low-Cost Microstrip Patch Antenna Based Metamaterials for Non-Invasive Breast Tumor Detection

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Abstract: ***Microstrip antennas have been widely used for various broadband purposes. Despite their many promises, their use in medical applications has been limited by their narrow bandwidth and loss in high frequency bands. This work aims to design a patch sensor, which is a low-cost microstrip sensor suitable for biomedical applications for the detection of breast cancer tumors. The proposed antenna sensor consists of three layers, i.e., ground, substrate, and microstrip sensor, which can be easily fabricated using standard printed circuit methods. A comparative study was carried out between two resonance frequencies at 1.8 GHz and 2.9 GHz, which-frequency were investigated with special precision simulating the presence and absence of a tumor cell. Using CST Studio Suite 3D computer simulation technology software for electromagnetic field simulation and analysis, the results show that the model can detect tumor phase change detection and return loss depth. The result shows that the return loss of the antenna becomes lower -39 dB at 1.8 GHz and -12 dB at 2.9 GHz and the phase shift is observed in the presence of tumor cells. The differential absorption rate (0.746 and 0.934 W/kg) was also calculated and found to be within the acceptable range and not exceeding the standard value. Two parameters are considered in this study, namely frequency phase shift and depth reflection return loss. Taken together, this study concludes that a lower frequency band increases penetration depth but decreases resolution. At the same time, the higher frequency band provides better clarity, but reduces the ability to penetrate deeply, as observed in the frequency between 1.8 GHz and 2.9 GHz. The proposed work could provide a way to design electromagnetic sensors for biomedical applications.***

Keywords: Antenna; Specific Absorption Rate; Breast Tumor; Phase Shift; Return Loss.

I. INTRODUCTION

Cancer has been the most prominent health concern over the past 50 years and has the potential to impact various healthy organs in the body. Nevertheless, breast cancer remains the most predominant form of cancer among women internationally [1, 2].

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Breast cancer has caused the deaths of around 8.2 million individuals [3]. Regrettably, over 1.8 million cases of breast cancer are stated globally each year, and it is projected that the amount of people affected by breast cancer will increase from 14 million to 22 million over the next twenty years, with the possibility of further escalation [4, 5]. Because breast cancer has a high rate of occurrence, it is regarded as one of the highest perilous forms of cancer, notably for women. As a result, women need to undergo regular screening and examinations.

One of the most common techniques to diagnose breast cancer is Mammography via X-ray [6], which seen as the only way for women who do not show early symptoms. Nevertheless, this approach may lead to worsening the quality of life for patients because of incorrect diagnoses and inaccurate initial test results [7]. Another method to diagnose breast malignant tumor is ultrasound imaging, which occasionally suffers from recognizing the differences between a diseased and healthy cell especially in the initial phase [8]. Another advance technique is the MRI magnetic resonance imaging which is used for women with dense breast tissue. Although MRI is highly sensitive, it is also costly and complex. Furthermore, the tumor cannot be precisely located using this technique, potentially resulting in incorrect extraction or another difficulty [10].

There are limitations in former techniques such as erroneity, position, big equipment, complex and costly techniques. A new technique has been used as a promising technique with low cost, reduced complexity, high information rate precision, non-ionizing, and low power intensity namely microwaves [6, 8, 9, 11, 26, 27, 28]. Microwave imaging (MWI) systems are currently gaining considerable interest as a different method for detecting breast cancer [12] and consider to be early diagnosis technique for breast cancer. When breast cancer is identified early, survival rates can be as high as 97%. The MWI is a modern, dependable, and very effective method for identifying breast cancer early on [10, 13]. MWI is dependent on Metamaterial (MTM), an electromagnetic substance that possesses distinctive properties rarely seen in the natural world [13]. The Metamaterials are synthesis objects that reveal extraordinary characteristics such as negative permeability ($\mu < 0$), negative permittivity ($\varepsilon < 0$) and negative refractive index [14] in the desired frequency range [15, 16]. The MTMs are used in a diversity of practical applications, including microwave and terahertz applications [16, 17, 18], antennas [19], sensors [14-16], sensitive detectors [17], polarization transducers [20, 21], radar [20], absorbers [22] and cloaking [23].

The most valuable way to treat breast cancer is through early detection, as survival ratios can increase when the cancer is caught early [7]. This paper presents the numerical design of a novel design of patch-antenna for detection of breast cancer using microwave. This method and layout offer a dependable and extremely effective means of identifying breast cancer in its initial stages. This study is thought to be valuable for biomedical purposes, including the detection of cancer tumor cells. The Studio Suite CST analysis and simulation software was utilized to model and simulate numerical outcomes.

II. METHOD

The central objective of this project is to construct a microstrip patch antenna for detecting and differentiating alterations in backscattered signals from changes in the electrical characteristics of cells and tissues. The backscattered signal can be used to differentiate between normal and cancerous cells based on alterations in the electrical properties of tissues. The patch antenna is crucial and must be carefully evaluated in the scheme.

The underlying concept of such technique is producing a microwave electromagnetic signal, which is then transmitted to a human cell. Some of the signal reflects towards the antenna based on the cell's dielectric properties. Research [5, 24] has shown that the dielectric properties of a cancer cell are higher than those of a normal cell. Therefore, a clear indication of a cancerous cell is shown by a notable backscattered microwave signal. Moreover, significant evidence such as the phase shift and return loss, can be gathered from the scattered back signal, representing the presence of a tumor cell. Addition considerations are counted in the antenna design such as directivity of radiation, the gain, mismatching, SAR absorption rate.

A. Patch Section Formula

Due to its thin profile and ease of configuration and manufacturing, the microstrip patch antenna was selected for its suitability in compact design. The design utilizes a substrate that made of fire resistant epoxy resin and fiberglass composite (FR4). with a dielectric constant of ε_r=4.3, a thickness of h=1.6mm, and a loss tangent of 0.025. Furthermore, a copper ground layer with a thickness of 0.035 is utilized, and a microstrip line feed is employed as the primary feeding method to ensure a 50Ω impedance match. The formula provided is for the dimensions of the patch [25][29][30],

Length of patch:

$$L = \frac{1}{2f_r\sqrt{\varepsilon_{reff}}\sqrt{\mu_0\varepsilon_0}} = -2\Delta L \quad (1)$$

Where h is substrate thickness:

$$\varepsilon_{reff} = \frac{\varepsilon_{r+1}}{2} + \frac{\varepsilon_{r-1}}{2}\left[1 + 12\frac{h}{w}\right]^{-1/2} \quad (2)$$

$$\frac{\Delta L}{h} = 0.412\frac{(\varepsilon_{reff}+0.3)(\frac{w}{h}+0.264)}{(\varepsilon_{reff}-0.258)(\frac{w}{h}+0.8)} \quad (3)$$

Wide of patch (Wp):

$$w = \frac{1}{2f_r\sqrt{\mu_0\varepsilon_0}}\sqrt{\frac{2}{\varepsilon_r+1}} = \frac{v_0}{2f_r}\sqrt{\frac{2}{\varepsilon_r+1}} \quad (4)$$

where ε_r = dielectic constant of substrate
ε_{reff} = Effective dielectric constant
W_p = Width of the patch

B. Substrate and Ground Planes

Length of substrate plane (Ls):

$$L_s = 6h + L \quad (5)$$

Wide of substrate plane (Ws):

$$W_s = 6h + W \quad (6)$$

The size of the ground is similar to the width of the substrate, but the length has been shortened to enhance performance and adjust the resonance frequency to the desired range.

C. Antenna Sensor Design

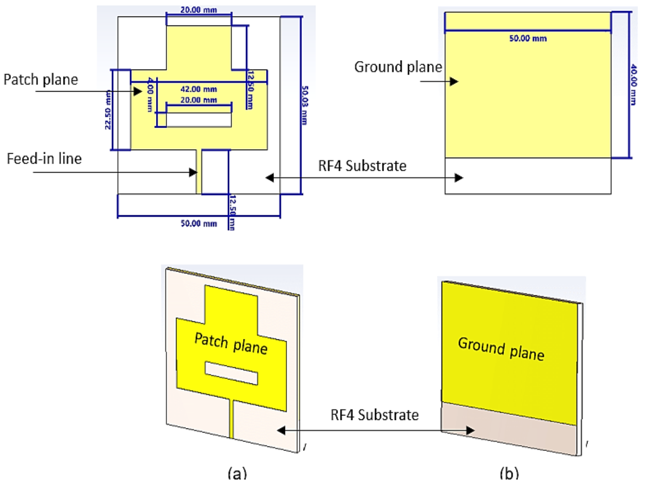

Figure 1. Microstrip Antenna Structure, (a) Frontage and (b) Backside

Figure 1 shows the layers of the design, which contains three deposits, ground, substrate, and patch layers. The dimension of the substrate is 50x50 mm while the patch sensor is 42x45 mm. Figure 1 illustrates that the ground surface is modifying by cut off the small part from the downside as well as adding a rectangular opening slot on the patch surface. Based on its design, the proposed design was created with various resonant frequencies, specifically at 1.8 GHz and 2.9 GHz. All modifications in the structure design such as slots and cut off will improve and enhance the efficiency of the antenna, regarding gain, radiation and return-lose.

III. RESULTS

In this section a comparison study of simulated results of the antenna sensor has been discussed for both resonance frequencies at 1.8 and 2.9 GHz with the present of tumor cell and without as shown in figure 2.

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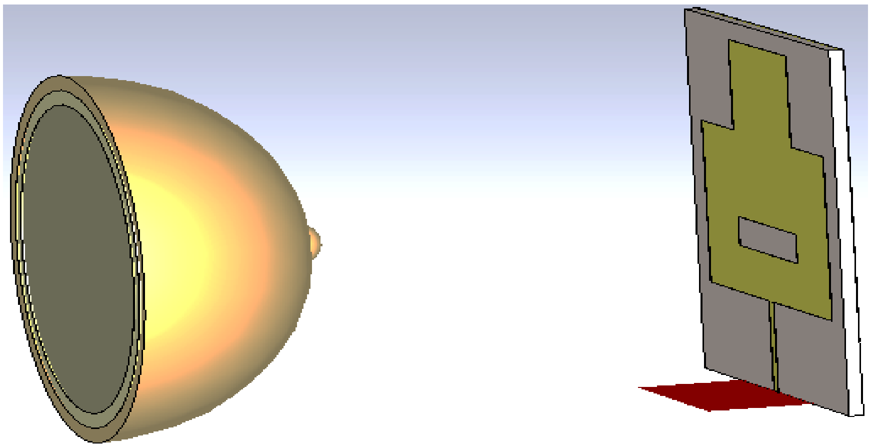


Figure 2. Antenna Sensor with Breast Model

Figure 2 shows that the phantom breast consists of three layers, which are the outer skin (breast skin), the fibroglandular layer of the breast, and the inner layer, which is breast fat. Figure 3 illustrates the breast layers.

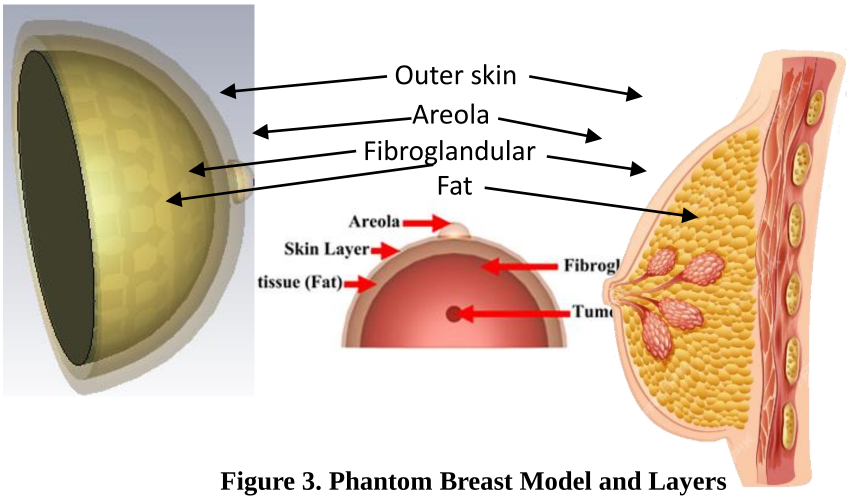
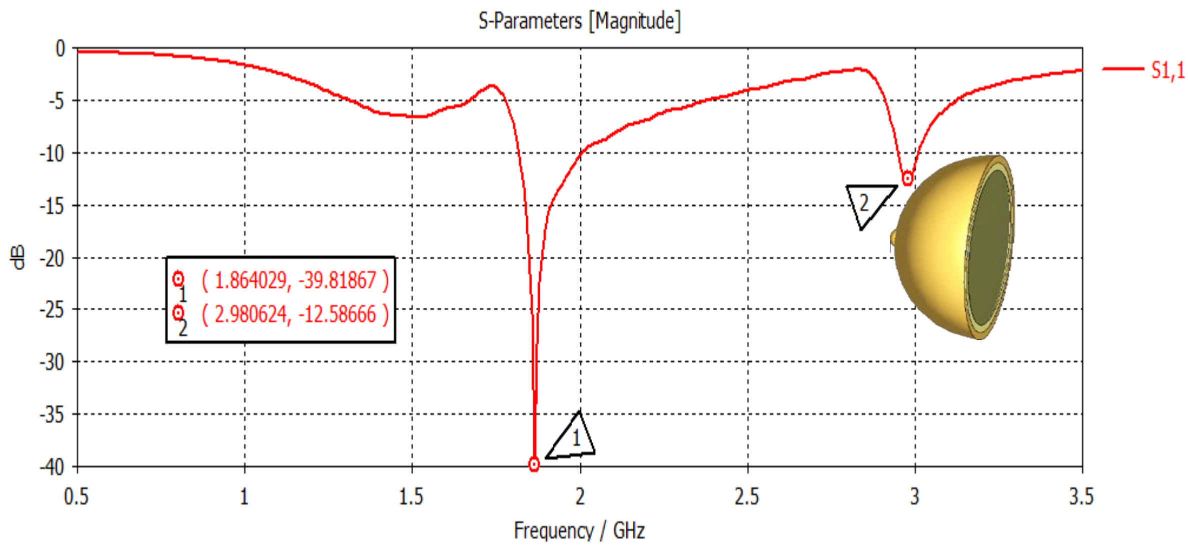


Figure 3. Phantom Breast Model and Layers

A. Return Loss:

On of the most important parameter is the return loss (S11) that present significantly at resonant frequencies of 1.8 GHz and 2.9 GHz. All reflection factors are less than -10dB, which meets the criteria. Figure 4 shows the S11 profile curves in both the ordinary breast in Figure 4 (a) and the cancerous breast in Figure 4 (b).



(a)

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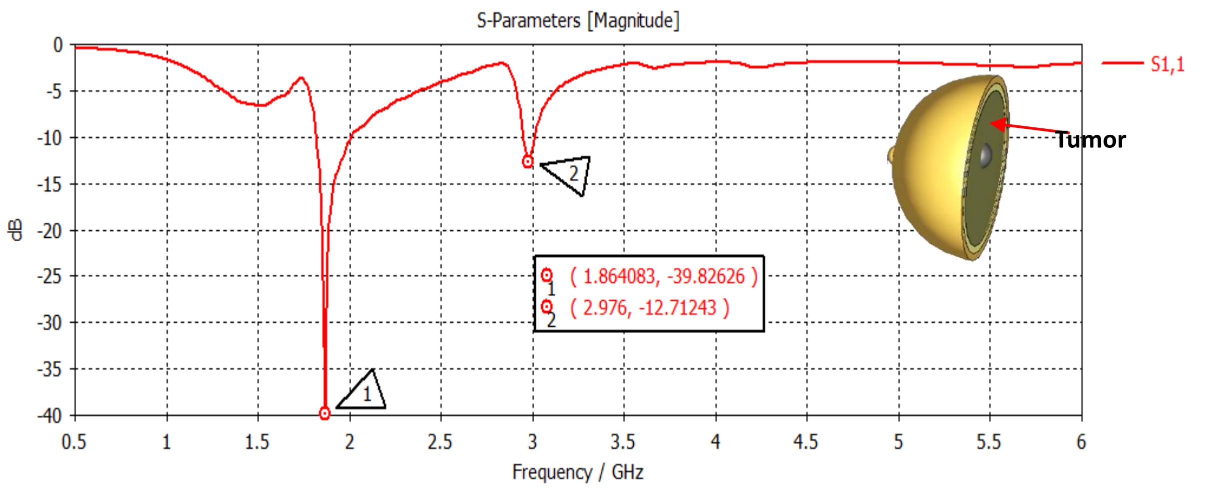

(b)

Figure 4. Parameter of (S11), (a) Not Including a Tumor Cell and (b) with Tumor Cell

Figure 4 shows the phase shift at 1.8 GHz, between a normal and affected cell which is very small around 54Hz, whereas at 2.9 GHz, the phase difference is around125 MHz. Even though the return loss at 1.8 GHz is -39dB which is much better than the S11 (-12dB) at 2.9 GHz by around -27dB, however the resolution of higher band frequency is significantly better. Furthermore, the deepness value of S11 is an additional consideration that is used as an indicator of tumor cells. At the frequency of 1.8 GHz, the depth deference is 0.0076dB (with/without tumor cell) whereas at resonance frequency of 2.9 GHz is 0.13dB.

B. The Voltage Standing Wave Ratio (VSWR)

The VSWR shows how well an antenna and its connecting feed line match and should ideally be kept within an acceptable range. less than 2 for the desired resonant frequency. Therefore, the results of the simulated antenna sensor depicted in the Figure 5 below.

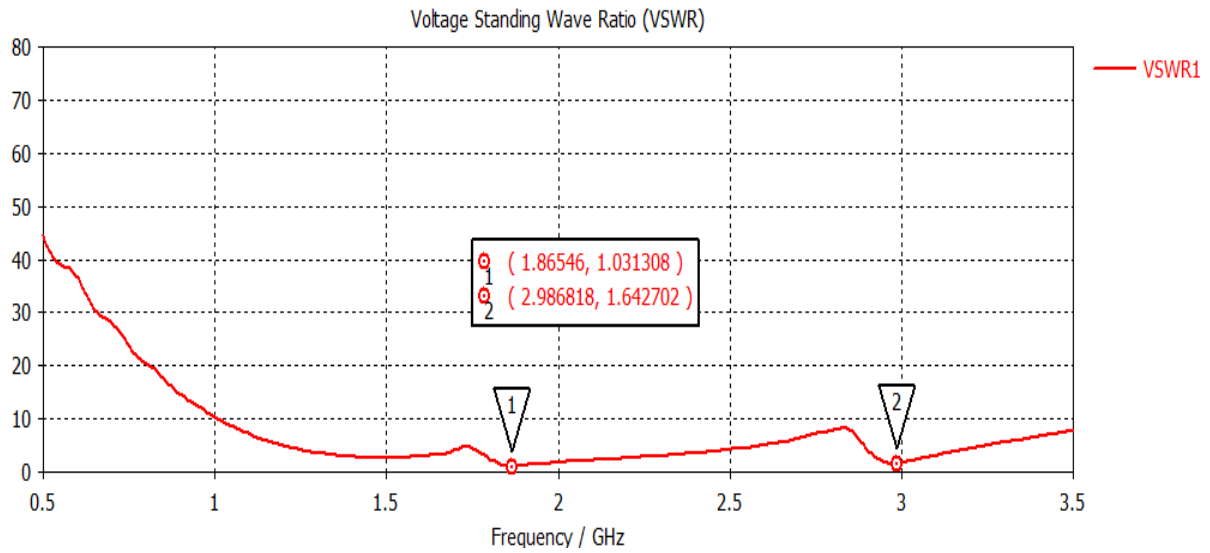

Figure 5. The Voltage Standing Wave Ratio (VSWR)

At both frequencies of 1.8 and 2.9 GHz, the VSWR values are 1.03 and 1.64 respectively. A VSWR value below 2 is deemed appropriate for the majority of antenna uses. The antenna can be considered to have a "good quality match and balance", however, when the VSWR value goes beyond 2, it implies that the antenna is properly tuned. The values of VSWR are less than 2 at both resonance frequencies which reveal that the design structure in good match and acceptable range.

C. Radiation Pattern

Measurements are recorded in tables for spherical coordinates theta and phi. This is how spherical coordinates correspond to Cartesian axes: If Theta is 0, it represents a full circle (360 degrees) and if Phi is 0, it represents the x-z plane. Fi at 90 corresponds to the y-z plane, while Theta at 90 represents the x-y plane. The x-z plane (ϕ = 0) is known as the E-plane and the y-z plane (ϕ = 90) is known as the H-plane. Figure 6 shows the radiation pattern of the proposed antenna in the x-z plane (E plane) and y-z plane (H plane). In addition, Figure 6 shows the 3-dimensional radiation pattern. E and H level beams are preferred because the main spokes remain stable when the beams are wide-sided.

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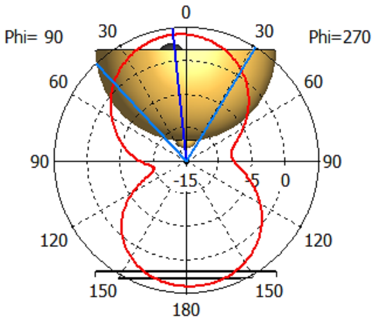
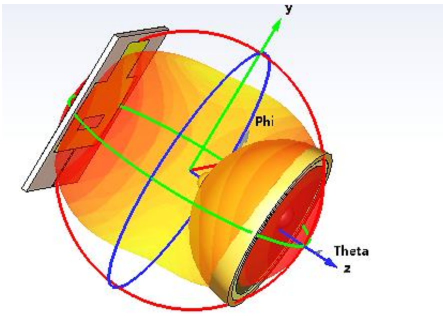


(a)



(b)

Figure 6. Radiation Shape at 1.8 GHz in H-Plane (y-z Plane) and E-Plane (x-z Plane)

The main portion magnitude = 3.94dBi as seen in figure 6 (a), the main lobe direction = 6 deg. and the angular width (3dB) = 74.4 deg. The gain and directivity pattern are simulated and plotted for all resonance frequencies. The observed shows that the directivity at 1.8 GHz and at 2.9 GHz are 3.773dBi and 3.264dBi respectively. Whereas the gain at 1.8 GHz is 0.995dBi and at 2.9 GHz is 1.804dBi. All above calculations with presence of tumor cell.

D. Specific Absorption Rate (SAR)

The absorption rate of radiation, especially SAR, is one of the most important parameters to consider. To avoid negative health effects, the absorption of the antenna must not exceed 2 W/K. The IC on Non-Ionizing Radiation Protection (ICNIRP) has advised this value as a limit in 1998. The absorption index is assessed by dividing the total power absorbed by the human body by the person's weight. To calculate SAR, you need to input electric field (measured in V/m), material conductivity (measured in S/m) and mass density (measured in kg/m3) into CST simulations.

The local specific absorption rate (SAR) is determined as a numeric value for each volume element and transforms into a function that represents the distribution of energy in space. Local SAR is the term used to refer to the mass average value within a specific tissue volume for this function. The average local SAR values are calculated in tissue masses of approximately 10g as outlined in the TTCA No. In 1989 and then in 1995, these values were established by European standards organizations (CENELEC), while the value of 1g was set by the United States' ANSI/IEEE C95.1-1992. A cuboid with an average volume is being utilized. Therefore, this study has determined and provided the maximum specific absorption rate (SAR) values for 10g and 1g masses as 0.746 W/kg and 0.934 W/kg, respectively.

In simpler words, SAR measures how quickly the body absorbs RF energy. In countries where the limit is based on an average of 1 gram of tissue, the SAR limit is 1.6 watts per kilogram, while in countries where the limit is based on an average of 10 grams of tissue, the SAR limit is 2.0 watts per kilogram. Therefore, the antenna design presented in this study is appropriate for use in the field of biomedicine, as both SAR values at 10g and 1g do not surpass 1.6 W/kg.

IV. DISCUSSION

The proposed design was modeled using CST-studio. At first, the patch antenna sensor was simulated with a full ground plane and with no slot on the patch-sensor. By using the full ground plane, the S11 was remarkable and more than -30dB but on the other hand the SAR radiation was more than standard value of 1.6 w/kg. However, after removing 10 mm from one side of the ground plane, the SAR radiation became in suitable range which is less than 1.6 w/kg.

Moreover, the frequency was around 6 GHz and distant from lower band frequency which is beneficial for biomedical purposes. Then, a slot rectangular of 20 mm width and 4 mm length was introduced on the patch antenna to enhance the performance. The frequency is moved down to a lower band frequency around ~3 GHz. Two resonance frequencies of 1.8 GHz and 2.9 GHz were introduced. Lowering the frequency increases the penetration depth but decreases the resolution. A comparative study between 1.8 GHz and 2.9 GHz showed that the higher frequency gives better resolution but less penetration depth. Using lower frequencies allows for deeper penetration with less loss, while higher frequencies provide better resolution but with limited phase shift and depth value. Therefore, the frequencies of 1.8 and 2.9 GHz have been chosen as the best option for imaging normal and tumor breast cells at a depth of 3-5cm.

Therefore, the penetration of high band frequency will be less, and this could be resolved by mounted different patch sensors around the breast. However, if the tumor is hidden in depth, then the lower band frequency could be used for greater deep penetration.

The difference is approved between S11 and its depth value as well as the phase shift in the frequency are observed due to the presence and absence of tumor cell. These results are acceptable and require further investigation into practical use.

V. CONCLUSION

In summary, a novel design and inexpensive antenna sensor were created and tested for detecting microwave breast cancer at frequencies of 1.8 and 2.9 GHz. CST software was employed for the creation and simulation of the structure. The antenna patch accomplished well return losses S11 of -39dB at the lowest frequency while at higher frequencies band is around -12dB.

The return loss depth in higher band is less than on the lower band frequency, while the higher band frequency affords identifiable detection and higher resolution more than the lower band frequency. A comparison study of two resonance frequencies was conducted. A phantom breast with lumps cell and without tumors were assessed to confirm the validity of the method. The parameters such as directivity, gain SAR and VSWR were taken into consideration in this design. The proposed design is a suitable alternative for use in biosensor applications and microwave detection of breast cancer.

DECLARATION STATEMENT

Funding	No, I did not receive.
Conflicts of Interest	No conflicts of interest to the best of our knowledge.
Ethical Approval and Consent to Participate	No, the article does not require ethical approval and consent to participate with evidence.
Availability of Data and Material	Not relevant.
Authors Contributions	I am only the sole author of the article.

REFERENCES

1. Harbeck, N.; Penault-Llorca, F.; Cortes, J.; Gnant, M.; Houssami, N.; Poortmans, P.; Ruddy, K.; Tsang, J.; Cardoso, F. Breast cancer. Nat. Rev. Dis. Primers 2019, 5, 66. https://doi.org/10.1038/s41572-019-0111-2
2. Waks, A.G.; Eric, P. Winer, Breast Cancer Treatment: A Review. JAMA 2019, 321, 288–300. [PubMed] https://doi.org/10.1001/jama.2018.19323
3. Stewart, B.W.; Wild, C.P. World Cancer Report; World Health Organization: Geneva, Switzerland, 2014.
4. Siegal, R.; Miller, K.D.; Jemal, A. Cancer statistics, 2012. CA Cancer J. Clin. 2014, 64, 9–29. [PubMed] https://doi.org/10.3322/caac.21208
5. Zerrad, F.E.; Taouzari, M.; Makroum, E.M.; el Aoufi, J.; Islam, M.T.; Ozkaner, V.; Abdulkarim, Y.I.; Karaaslan, M. Multilayered metamaterials array antenna based on artificial magnetic conductor's structure for the application diagnostic breast cancer detection with microwave imaging. Med. Eng. Phys. 2022, 99, 103737. https://doi.org/10.1016/j.medengphy.2021.103737
6. Alibakhshikenari, M.; Virdee, B.S.; Shukla, P.; Parchin, N.O.; Azpilicueta, L.; See, C.H.; Abd-Alhameed, R.A.; Falcone, F.; Huynen, I.; Denidni, T.A.; et al. Metamaterial-Inspired Antenna Array for Application in Microwave Breast Imaging Systems for Tumor Detection. IEEE Access 2020, 8, 174667–174678. https://doi.org/10.1109/ACCESS.2020.3025672
7. Aldhaeebi, M.A.; Alzoubi, K.; Almoneef, T.S.; Bamatraf, S.M.; Attia, H.; Ramahi, O.M. Review of Microwaves Techniques for Breast Cancer Detection. Sensors 2020, 20, 2390. https://doi.org/10.3390/s20082390
8. Hossain, A.; Islam, M.T.; Islam, M.T.; Chowdhury, M.E.H.; Rmili, H.; Samsuzzaman, M. A Planar Ultrawideband Patch Antenna Array for Microwave Breast Tumor Detection. Materials 2020, 13, 4918. [PubMed] https://doi.org/10.3390/ma13214918
9. Rao, P.K.; Yadav, A.R.; Mishra, R. AMC-based antenna sensor for breast tumors detection. Int. J. Microw. Wirel. Technol. 2020,13, 954–961. https://doi.org/10.1017/S1759078720001609
10. Mahmud, M.Z.; Islam, M.T.; Misran, N.; Kibria, S.; Samsuzzaman, M. Microwave Imaging for Breast Tumor Detection Using Uniplanar AMC Based CPW-Fed Microstrip Antenna. IEEE Access 2018, 6, 44763–44775. https://doi.org/10.1109/ACCESS.2018.2859434
11. Islam, M.T.; Mahmud, M.Z.; Islam, M.T.; Kibria, S.; Samsuzzaman, M. A Low Cost and Portable Microwave Imaging System for Breast Tumor Detection Using UWB Directional Antenna array. Sci. Rep. 2019, 9, 15491. [PubMed] https://doi.org/10.1038/s41598-019-51620-z
12. Musa, N.; Yadgar, A.; Salah, S.; Olcay, A.; Rashad, H.; Bhargav, A.; Cristian, R., Low-Cost Antenna-Array-Based Metamaterials for Non-Invasive Early-Stage Breast Tumor Detection in the Human Body. Biosensors 2022, 12, 828. https://doi.org/10.3390/bios12100828
13. Langtry, A. Understanding Cancer of the Breast; Irish Cancer Society: Dublin, Ireland, 2008
14. Abdulkarim, Y.I.; Deng, L.; Yang, J.; Çolak, ¸S.; Karaaslan, M.; Huang, S.; He, L.; Luo, H. Tunable left-hand characteristics in multi-nested square-split-ring enabled metamaterials. J. Cent. South Univ. 2020, 27, 1235–1246. https://doi.org/10.1007/s11771-020-4363-5
15. Abdulkarim, Y.I.; Dalgaç, ¸S.; Alkurt, F.O.; Muhammadsharif, F.F.; Awl, H.N.; Saeed, S.R.; Altınta¸s, O.; Li, C.; Bakır, M.; Karaaslan, M.; et al. Utilization of a triple hexagonal split ring resonator (SRR) based metamaterial sensor for the improved detection of fuel adulteration. J. Mater. Sci. Mater. Electron. 2021, 32, 24258–24272. https://doi.org/10.1007/s10854-021-06891-6
16. Abdulkarim, Y.I.; Deng, L.; Karaaslan, M.; Unal, E. Determination of the liquid chemicals depending on the electrical characteristics by using metamaterial absorber based sensor. Chem. Phys. Lett. 2019, 732, 136655. https://doi.org/10.1016/j.cplett.2019.136655
17. Abdulkarim, Y.I.; Muhammadsharif, F.F.; Bakır, M.; Awl, H.N.; Karaaslan, M.; Deng, L.; Huang, S. Hypersensitized metamaterials based on a corona-shaped resonator for efficient detection of glucose. Appl. Sci. 2020, 11, 103. https://doi.org/10.3390/app11010103
18. Abdulkarim, Y.I.; Xiao, M.; Awl, H.N.; Muhammadsharif, F.F.; Lang, T.; Saeed, S.R.; Alkurt, F.Ö.; Bakır, M.; Karaaslan, M.; Dong, J. Simulation and lithographic fabrication of a triple band terahertz metamaterial absorber coated on flexible polyethylene terephthalate substrate. Opt. Mater. Express 2021, 12, 338–359. https://doi.org/10.1364/OME.447855
19. Abdulkarim, Y.I.; Awl, H.N.; Muhammadsharif, F.F.; Karaaslan, M.; Mahmud, R.H.; Hasan, S.O.; I¸sık, Ö.; Luo, H.; Huang, S.; de Cos Gómez, M.E. A Low-Profile Antenna Based on Single-Layer Metasurface for Ku-Band Applications. Int. J. Antennas Propag. 2020, 2020, 8813951. https://doi.org/10.1155/2020/8813951
20. Ali, H.O.; Al-Hindawi, A.M.; Abdulkarim, Y.I.; Nugoolcharoenlap, E.; Tippo, T.; Alkurt, F.Ö.; Altintas, O.; Karaaslan, M. Simulated and experimental studies of a multi-band symmetric metamaterial absorber with polarization independence for radar applications. Chin. Phys. B 2022, 31, 058401. https://doi.org/10.1088/1674-1056/ac2b1c
21. Cheng, Y.; Fan, J.; Luo, H.; Chen, F. Dual-band and high-efficiency circular polarization converter based on anisotropic metamaterial, IEEE Access 2019, 8, 7615–7621. https://doi.org/10.1109/ACCESS.2019.2962299
22. Liang, Y.; Koshelev, K.; Zhang, F.; Lin, H.; Lin, S.; Wu, J.; Jia, B.; Kivshar, Y. Bound states in the continuum in anisotropic plasmonic metasurfaces. Nano Lett. 2020, 20, 6351–6356. https://doi.org/10.1021/acs.nanolett.0c01752
23. Ramaccia, D.; Sounas, D.L.; Alù, A.; Bilotti, F.; Toscano, A. Nonreciprocity in antenna radiation induced by space-time varying metamaterial cloaks. IEEE Antennas Wirel. Propag. Lett. 2018, 17, 1968–1972. https://doi.org/10.1109/LAWP.2018.2870688
24. Hussein, M.; Awwad, F.; Jithin, D.; el Hasasna, H.; Athamneh, K.; Iratni, R. Breast cancer cells exhibits specific dielectric signature in vitro using the open-ended coaxial probe technique from 200 MHz to 13.6 GHz. Sci. Rep. 2019, 9, 4681. https://doi.org/10.1038/s41598-019-41124-1
25. Balanis, Constantine A. Antenna Theory: Analysis and Design. 3rd ed. Hoboken, NJ: John Wiley, 2005.
26. Rao, S. V. R., Prasad, A. M., & Rani, Ch. S. (2019). Antenna Array Weight Synthesis for Low Side Lobe Levels using Window Functions. In International Journal of Engineering and Advanced Technology (Vol. 9, Issue 1, pp. 3074–3081). https://doi.org/10.35940/ijeat.a1664.109119
27. Jayanth, M. V., Harika, B. S. L., Aashika, B., Lakshman, P., & Santosh, G. S. (2019). Position only Antenna Array Synthesis using Normal Distributed Invasive Weed Optimization. In International Journal of Innovative Technology and Exploring Engineering (Vol. 9, Issue 2, pp. 3277–3280). https://doi.org/10.35940/ijitee.b6641.129219
28. Ram, G. C., kumar, D. G., & Raju, G. R. L. V. N. S. (2020). Synthesis of Linear Antenna Array with Optimal SLL and Beam Width. In International Journal of Recent Technology and Engineering (IJRTE) (Vol. 9, Issue 1, pp. 391–395). https://doi.org/10.35940/ijrte.a1612.059120

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DOI: 10.35940/ijitee.A9763.1213123
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29. Bhatia, M., Chakraborty, A., Sharma, P., & Chauhan, B. (2020). Spiral Antenna with Hilbert Antenna for Body Worn Application. In International Journal of Soft Computing and Engineering (Vol. 10, Issue 1, pp. 1–5). https://doi.org/10.35940/ijsce.a3432.0710120
30. Kundu, S. K., & Singhal, P. K. (2019). Design of slit loaded Planar and Curved Patch Antenna. In International Journal of Innovative Science and Modern Engineering (Vol. 6, Issue 1, pp. 11–14). https://doi.org/10.35940/ijisme.a1139.086119

AUTHOR PROFILE

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