Investigation on Electromagnetic Properties of PLA/Carbon/Copper Antennas for Breast Cancer Detection

Emine Avşar Aydin[1*], Ahmet Refah Torun[2]
1- Adana Alparslan Türkeş Science and Technology University, Department of Aerospace Engineering, Balcalı Mh., Sarıçam/Adana, 01250, Turkey.
Email: eaydin@atu.edu.tr, rasvaenime@gmail.com (Corresponding author)
2- Adana Alparslan Türkeş Science and Technology University, Department of Aerospace Engineering, Balcalı Mh., Sarıçam/Adana, 01250, Turkey.
Email: artorun@atu.edu.tr

Received: August 2020 Revised: September 2020 Accepted: November 2020

ABSTRACT:
Breast cancer is the most common cancer of women in the globe. Microwave imaging has low power and longer wavelength signals to receive information about breast tissues and guarantees a safer and more accurate modality for regular breast control. So, the antenna is a crucial element in the microwave imaging system. This study involves analysis of the simulation results of the linear and planar microstrip array antennas in terms of high gain. In the series antenna design stage, the antenna models with high gain and directional radiation are aimed. 1x4 and 2x2 array antenna models are prepared with PLA/Carbon insulating material. Array antennas, three-dimensional full-wave electromagnetic structure analysis are designed using the CST (Computer Simulation Technology) Microwave Studio program. In the design phase, the transmission line losses of the array antennas are tried to be optimized by using T-junction and Wilkinson power divider techniques and impedance matching is realized. Also, the redundant areas in the turns are removed to minimize the undesirable reflections in the transmission line and to reduce the capacitive loading. Since the 1x4 array antenna performs better than the 2x2 array antenna, it was preferred for breast cancer simulation.

KEYWORDS: Gain, Impedance Matching, Microwave Antenna Arrays, Microwave Imaging, Tumor.

1. INTRODUCTION

Breast cancer is the most frequent type of cancer for women in the world, although it can also so be rarely seen on men as well [1]–[7]. It occurs through the uncontrolled cell division around the breast tissue. The cancer cell are usually located in the milk drainage channels and mostly the women after the menopause period are subject to this kind of dissease. As the breast cancer does not cause pain, the mamography scan is of the utmost importance to detect the tumor in its early stage. The early diagnosis of the malign tissue increases the rate of curing up to 90%.

The utilization of the microwave imaging techniques in the fields of such as behind the concrete imaging systems, defense industry and radar applications, detection of banned substances at security points, underground imaging processes, non-destructive detection and inspection of materials, quality control tests of foods, biomedical applications and many other areas has gained importance in the recent years and the research efforts on the microwave imaging are increasing as well [8]–[13].

For instance, the use of microwave techniques to detect breast cancer at its early stage is a popular topic on which the researchers are currently working. One of the contributions reported to extend the current studies is related to the design of the most suitable antenna type required for sending and receiving of the microwave signals [14], [15].

The basic principle of the microwave imaging technique is to send the signal to the material on the target with the transmitting antenna and to receive the scattered signal with

the receiving antenna. Therefore, the selection of the antenna to be used plays an important role in the measurements.

Although different types of antennas are available such as horn, dipole, vivaldi and butterfly, the researchers prefer to design and use their own micro-strip antennas in order to decrease the costs and increase the mobility [16].

The wide broadband microwave imaging systems need low and high frequency signals to achieve a good result. The low frequency band provides the necessary penetration depth, while the high frequency band

Paper type: Research paper
DOI: https://doi.org/10.29252/mjtd.10.1.1
How to cite this paper: E. Avşar Aydin , A. Refah Torun, **"Investigation on Electromagnetic Properties of PLA/Carbon/Copper Antennas for Breast Cancer Detection"**, *Majlesi Journal of Telecommunication Devices*, Vol. 10, No. 1, pp. 1-7, 2021.

provides a sufficient resolution for the image to be created. Thus, the detection of the objects that are both deep in position and small in size is successfully realized [17], [18].

The conventional micro-strip antenna has the drawback that it cannot operate in a wide-band range. For this reason, in order to make the antenna suitable for microwave imaging system, it is necessary to increase the bandwidth and efficiency by performing various modifications. There are proposed methods to improve the performance of the antenna and one of the most effective is using special substrate material itself [10], [19]–[21]. The widely used FR4 substrate is made up of epoxy matrix reinforced with a woven glass fabric. Beside its availability and relatively low cost, there are couple of drawbacks such as low recyclability due to the thermoset matrix, over-engineering in terms of high strength and no contribution to the antenna because of its low conductivity and the lack of tailored design. In order to overcome these points, the 3D printed PLA/Carbon thermoplastic composite structure is proposed which can easily be recycled and tailored in terms of the requirements from the antenna.

With the development of wireless systems in the new generation communication networks, the tendency for simple-looking, integrated structure, and high-gain antenna designs has increased. The Microstrip Antenna (MA), which is used in the biomedical area, missile, rocket and satellite technologies, radar systems and many applications, has a good position among the antenna models in meeting these needs [22]. The narrow bandwidth and low gain values of the MAs, which are considered to be disadvantageous, have achieved an excellent performance by using different methods such as changes in their geometrical structures and special dielectric material selection. MAs are mainly fed as a microstrip line or coaxial as feeding technique [23]. In this study, the design and production of the uncomplicated, modified inset fed MA design have been made.

Different methods for MA analysis are available in the literature. The most popular of these methods are the transmission line model, the cavity model, and the full wave model. The transmission line model is the most basic and easy method, but it is capable of solving single-layer physical structures. However, the accuracy rate is relatively weak compared to other methods. The hollow model has higher accuracy, but this method is also insufficient for modeling multi-layer structures. The model with high accuracy is the full wave model in modeling multi-layer structures. But this model is complex [24]. In this study, the theoretical calculations are made regarding the transmission line model.

In wireless systems, communication is usually carried out with directional radiation antennas. The gain factor is an indication of how much the antenna is directional. Also, high-gain antennas provide more efficient operation in wireless communication systems. As known, MAs have low gain and generally single element MA cannot meet the desired requirements (gain, directivity). Therefore, the array of antennas created by the geometric placement of multiple-element MAs are needed. The array elements are selected symmetrically to obtain the radiation pattern of the antenna in the desired direction. Due to their ease of design and the geometrical structure, MAs are one of the most widely used array antenna types [25]. Linear microstrip arrays are used for fan-shaped scopes and may also form a building block for planar arrays. Planar microstrip arrays are used to create a pencil beam, and array elements can be fed in various ways [26]. In general, there are similar series of antenna studies in the literature. There are studies which include microstrip line feed as feeding technique and comparison as coaxial feed. FR4 and Rogers materials have been generally used in terms of insulating material in literature [27]–[30].

The article flow is organized as follows; Material and method section of the antenna to be designed, material selection of the substrate material, simulation and analysis of the program to be done, linear and planar array and array elements to be used in the placement of impedance matching techniques are described. Performance parameters and analysis results of 1x4 and 2x2 array antennas were evaluated in the application and performance section. In the conclusion and discussion section, the analysis, simulation, and comparison tables were interpreted.

2. MICROWAVE SYSTEM

A. Antenna Design

In the MA design, the material selection was made primarily for the radiation. The low cost and easily accessible PLA/Carbon thermoplastic composite substrate are preferred from commercially available materials and the relative dielectric constant, loss tangent, conductor thickness (*t = 0.64*) mm and insulator plate height (*h = 1.575*) mm are taken as material.

When calculating the physical parameters of the standard MA, which is modeled at 2.45 GHz, the transmission line model is taken as a reference [22]–[31]. While Fig. 1 shows the standard geometrical structure of this model and Fig. 2 shows gain of this model. The design relations (1-5) required to create the standard MA are shown below.

$$W_p = c\sqrt{\frac{\varepsilon_r+1}{2}}/2f_r \quad (1)$$

$$\varepsilon_{eff} = \left[\frac{\varepsilon_r+1}{2}\right] + \left[\frac{\varepsilon_r-1}{2}\right]\sqrt{\frac{1+12h}{W_p}} \quad (2)$$

$$L_p = \left[\frac{c}{2f_r\sqrt{\varepsilon_{eff}}}\right] - 2\Delta l \quad (3)$$

$$x_0 = \frac{c}{\sqrt{2\varepsilon_{eff}}}\frac{4{,}65x\,10^{-12}}{f_r} \quad (4)$$

$$y_0 = \frac{L_p}{\pi}\arccos\sqrt{\frac{Z_0}{Z_t}} \quad (5)$$

$$Z_0 = \frac{87}{\sqrt{\varepsilon_r+1{,}41}}\left(\frac{5{,}98h}{0{,}8W_0+t}\right) \quad (6)$$

W_p is the width of the MA patch used in the formula, $L_p$is the length of the MA patch, ε_{eff} is the effective value of the insulating material, c is the velocity of light in the cavity of the wave, f_r is the resonance frequency and Δl is the line expansion. W_0 is the width of feeding line, y_0 is the position of the feed point, x_0 is the gap between the feed point and the patch, Z_t is the existing antenna before the feed is added and Z_0 indicates the target input impedance.
There are different feeding methods in MAs. They are divided into contact and contactless feeding methods. The feeding method affects the antenna input impedance and radiation characteristics and therefore it is an important design parameter [32]. Due to their flexible structure such as impedance matching with the convenience of manufacturing and easy to design, addition feeding method from the contact feeding methods is preferred and the standard MA is designed [31].

Generally, in single-element applications, the antenna input impedance is selected as 50 ohm. Since the simulation results of MA modeled with the numerical values as a result of the theoretical calculations are not at the desired level, some parameters have been changed, and relevant results have been obtained. For the simulation results, high-frequency structure simulator (CST) [33], which is widely used in the analysis of electromagnetic structures and based on the finite element method, was used. Input and output parameters of the used MA are given in Table 1.

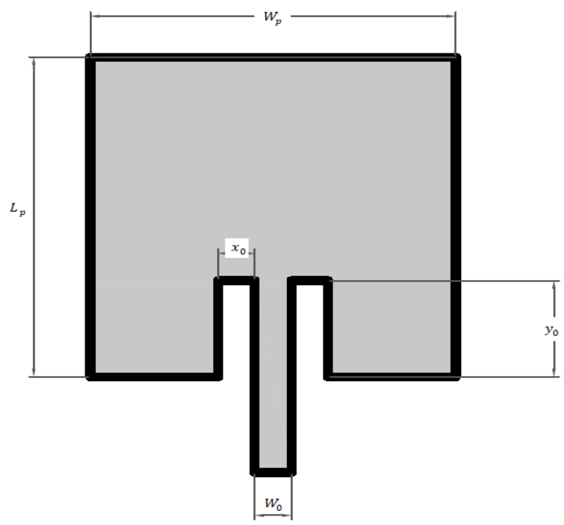

Fig. 1. The standard microstrip antenna.

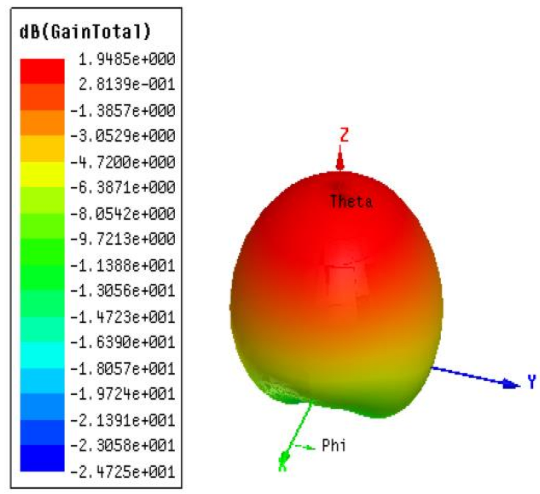

Fig. 2. Gain of the proposed antenna.

Table 1. The standard MA parameters.

Parameter	Values
Operating Frequency	2.45 GHz
Dielectric Constant	2.8
Insulation Material Thickness	1.525 mm
Conductive Copper Thickness	0.64 mm
Lost tangent (tanδ)	0.003
MA Patch Width	36.12 mm
MA Patch length	28.18 mm
Width of Feed Line	2.978 mm
Opening Point	1.75 mm
Feed Point Depth	7.25 mm
Input Impedance of Patch	54 ohm

Linear and planar array antennas have been designed by multiplying the number of elements that perform the radiation of the MA obtained by the transmission line model. The aim of the array antenna design is to achieve the highest gain and orientation with a minimum side lobe level. The linear array consists of the N element arranged along a line. The planar array consists of a combination of *NxM* elements along a plane. Planar arrays are more functional since they provide a symmetrical radiance that creates smaller side lobes. It is more convenient to control the radiation beam of the antenna with this configuration. When designing a linear or planar antenna, care must be taken that the distance between each element is less than or equal to the wavelength ($d \leq \lambda_0$) [34]. The distance between the elements $\lambda_0/2$ was taken for the proposed array antennas.

B. Impedance Matching

In the array antennas, the microstrip lines to which the radiating array elements are connected to each other are arranged to have a 50 ın input port. The array antennas are usually aligned using a quarter wave converter. Quarter wave converter uses one-fourth of the directed wave to accommodate the total antenna load in a transmission line which has different characteristic impedance. Quarter Wave the impedance value is found by the following (7-8) relations [22]–[25].

$$Z_0 = Z_I + \left[\frac{Z_L + jZ_I \tan(\beta l)}{Z_I + jZ_L \tan(\beta l)}\right] \quad (7)$$

$$Z_I = \sqrt{Z_0 Z_L} \quad (8)$$

While $\beta = 2\pi/\lambda_g$ is the number of waves, Z_L is the load impedance. When calculating the β value, the wavelength of the strip line (λ_g) must be different from the wavelength in the space (λ_0). Therefore, the wavelength should be taken into account considering the material in which the strip line is made.

A quarter wave converter was used when combining 1x4 and 2x2 array elements. A basic model of the quarter wave converter is shown in Fig. 3. The line width of the quad-wave transformer W_I and the line length L_I can be calculated with and (9-10) relations [25].

$$Z_I = \frac{60}{\sqrt{\varepsilon_r}} In\left[\frac{8h}{W_I} + \frac{W_I}{4h}\right] \quad (9)$$

$$L_I = \frac{\lambda_g}{4} = \frac{\lambda_0}{4\sqrt{\varepsilon_{eff}}} \quad (10)$$

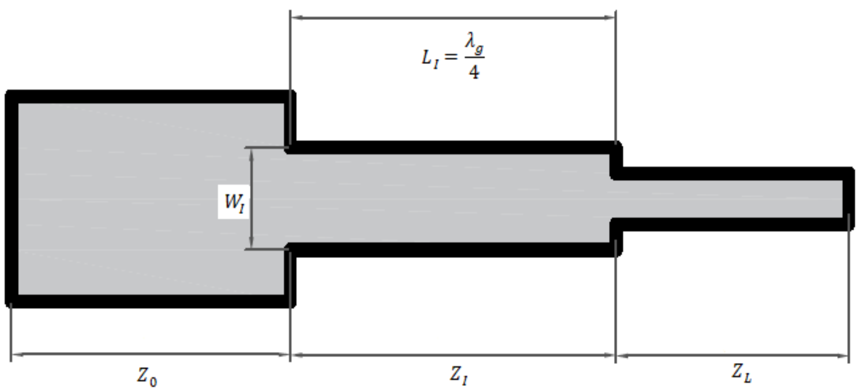

Fig. 3. Microstrip quarter wave converter.

Since linear or planar array antennas contain more than one turn as the number of elements increases, the microstrip transmission line is quite can become complicated. When designing the microstrip-fed array antenna, take into account the reflectance levels and the electrical lengths of the turns, and by lifting, the reflection level can be lowered. Also, unnecessary areas of bends and twists are removed and unwanted capacitive the load may be reduced slightly [35]. In Fig. 4, the inclined microstrip line turning model is shown. The best-harmonized twist length relations for a wide microstrip line geometry are also given in Eq. 11-13 [36].

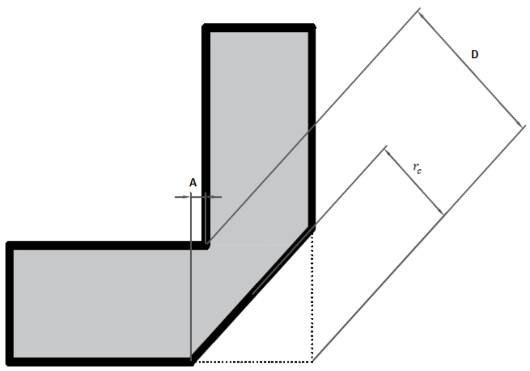

Fig. 4. Microstrip bending model.

$$D = W_i\sqrt{2} \quad (11)$$

$$r_c = D(0{,}52+0{,}65\exp(-1{,}35\frac{W_i}{h})) \quad (12)$$

$$A = (rc - \frac{D}{2})\sqrt{2} \quad (13)$$

In the above equations; D refers to the square diagonal length, r_c is the center corner bending height, A is the most appropriate bending area edge length, h is the thickness of the insulating layer and W_i is the microstrip line width. The array antennas designed according to these techniques and 1x4 array antenna is shown in Fig. 5.

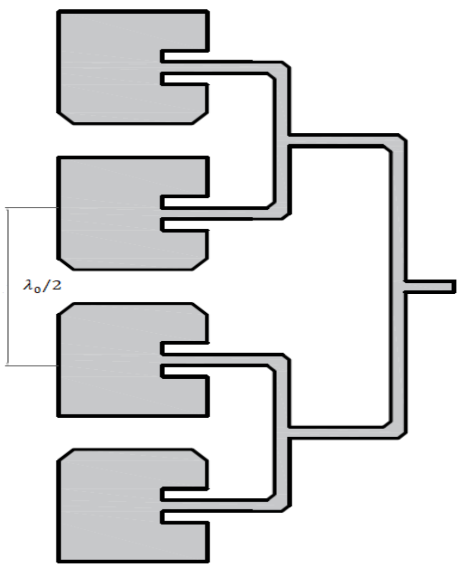

Fig. 5. 1x4 array antenna.

C. Breast phantom design

Various designs of breast phantom have been created by researchers for breast cancer detection studies [26]–[28]. Fig. 6 shows the design of 3-D hemispherical breast model with 50 mm height. It consists of 3 layers, such as skin, fat, and fibro-glandular tissue. Electrical properties of these tissues are given in Table 2 [37], [38].

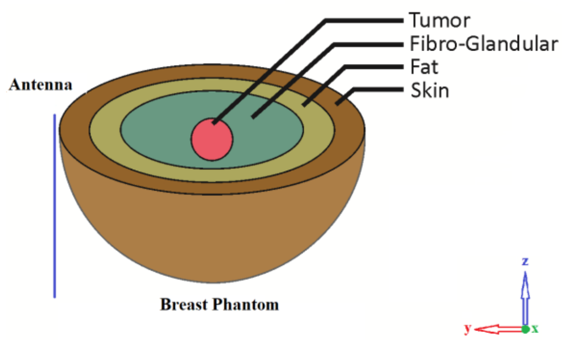

Fig. 6. Antenna on breast design in CST Microwave Studio.

Table 2. Electrical properties of breast tissues.

Breast Tissue	Dielectric	Conductivity(S/m)
Skin	36	4
Fat	9	0.4
Fibro-glandular	15	0.5
Tumor	50	4

3. RESULTS AND DISCUSSIONS

The most used parameter in antenna applications is S11. The loss of return with the other name S11 indicates the reflected energy of the antenna. Return loss from simulation results of 1x4 and 2x2 array antennas with 2.45 GHz with CST Microwave Studio Program was obtained. As shown in Table V, the 1x4 array antenna performs better than the 2x2 array antenna. Fig. 7 shows also return loss result of 1x4 array antennas. Therefore, 1x4 array antennas were used for breast cancer simulation in this study.

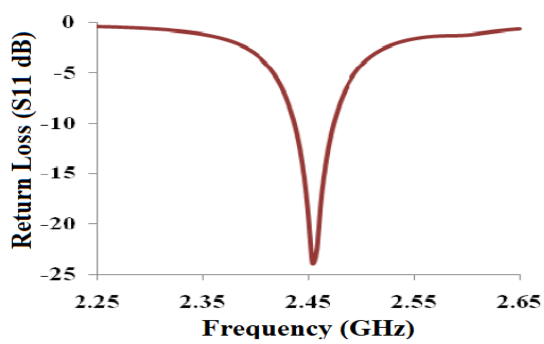

Fig. 7. Return loss result of 1x4 array.

Table 3. Comparison of simulation results of 1x4 array and 2x2 array antennas.

Antenna	Frequency (GHz)	S_{11}(dB)	Gain (dB)
2x2	2.44	-21.08	6.64
1x4	2.46	-24.96	10.01

Table 4 illustrates all results (electric field, magnetic field, and current density values) obtained and clarify the difference between results found in breast tissue with tumor and without tumor. It is seen that while standard antenna cannot help us to distinguish whether of the tumor, array antennas show us better results, mainly 1x4 array antennas.

Table 4. Results obtained from the electric and magnetic fields, and the current density for 1x4 array and 2x2 array antennas.

Antennas	Electric Field (V/m)		Magnetic Field (Am)		Current Density (AM^2)	
	Without tumor	With tumor	Without tumor	With tumor	Without tumor	With tumor
Standard	93.77	93.41	0.714	0.698	37.61	37.46
2x2	96.15	94.07	0.566	0.58	38.96	37.46
1x4	110.15	108.07	0.861	0.912	43:808	44.706

4. CONCLUSION

In this paper, the proposed antennas here are aimed to be used in a scanning system for detecting microwave breast cancer based on the antenna array. This system differs from the proposed antenna design with different antenna arrays. Firstly, a comparative study between two microstrip array antennas to select the perfect one that can be used in the microwave breast imaging system to recognize tumors developing in the women breast. 1x4 array and 2x2 array antenna studies were compared, and this study accepted the selection of 1x4 array antennas, which guarantees that we reduce the electric fields, magnetic fields and current density in healthy tissue with the presence of a malignant tumor in the breasts compared to a breast that will have a good appearance in tumors. In the second part, the simulation results of the antenna array show a good impedance matching and high gain. We believe that this array can be produced efficiently and easily for Microwave Breast Imaging compared to other existing imaging techniques. The antenna demonstrated a good return loss with acceptable gain.

5. ACKNOWLEDGMENT

This research was partially supported by Adana Alparslan Türkeş Science and Technology University Scientific Research Projects Commission. Project Number: 18119003.

REFERENCES

[1] M. Kaur, **“Calcification Detection in Breast Cancer,”** *Int. J. Psychosoc. Rehabil.*, pp. 5723–5732, 2020, doi: 10.37200/ijpr/v24i4/pr2020377.

[2] A. M. Hassan and M. El-Shenawee, “**Review of electromagnetic techniques for breast cancer detection,”** *IEEE Rev. Biomed. Eng.*, pp. 103–118, 2011, doi: 10.1109/RBME.2011.2169780.

[3] M. Xu, P. Thulasiraman, and S. Noghanian, **“Microwave tomography for breast cancer detection on cell broadband engine processors,”** *J. Parallel Distrib. Comput.*, Vol. 72, No. 9, pp. 1106–1116, 2011.

[4] A. Santorelli and M. Popović, **“SAR distribution in microwave breast screening: Results with TWTLTLA wideband antenna,”** in *Proceedings of the 2011 7th International Conference on Intelligent Sensors, Sensor Networks and Information Processing, ISSNIP 2011*, 2011, pp. 11–16, doi: 10.1109/ISSNIP.2011.6146531.

[5] A. Lazaro, D. Girbau, and R. Villarino, **“Simulated and experimental wavelet-based detection of breast tumor using a UWB radar,”** in *European Microwave Week 2010, EuMW2010: Connecting the World, Conference Proceedings - European Microwave Conference, EuMC 2010*, 2010, pp. 373–376.

[6] D. Zhang and A. Mase, **“Ultrashort-pulse radar system for breast cancer detection experiment: Imaging in frequency band,”** in *2011 China-Japan Joint Microwave Conference*, 2011, pp. 1–3.

[7] F. Delbary, M. Brignone, G. Bozza, R. Aramini, and M. Piana, **“A visualization method for breast cancer detection using microwaves,”** *SIAM J. Appl. Math.*, vol. 70, no. 7, pp. 2509–2533, 2010.

[8] Y. Deng and X. Liu, **“Electromagnetic imaging methods for nondestructive evaluation applications,”** *Sensors*, vol. 11, no. 12, pp. 11774–11808, 2011.

[9] J. J. Golezani, M. Abbak, and I. Akduman, **“A novel compact wideband directional monopole antenna for use in radar applications,”** 2012.

[10] M. H. Bah, J. Hong, and D. A. Jamro, **“Ground slotted monopole antenna design for microwave breast cancer detection based on time reversal MUSIC,”** *Prog. Electromagn. Res.*, vol. 59, pp. 117–126, 2015.

[11] A. G. Andukar, R. Deshmukh, and B. Bansod, **“A review on imaging techniques in food safety and its advancements,”** *Int. J. Adv. Res. Electr. Electron. Instrum. Eng.*, vol. 5, pp. 980–983, 2016.

[12] E. A. Jiya, N. S. N. Anwar, and M. Z. Abdullah, **"Detection of cracks in concrete structure using microwave imaging technique,"** *Int. J. Microw. Sci. Technol.*, vol. 2016, 2016.

[13] A. R. Çelik, M. B. Kurt, and S. Helhel, **"An overview of electromagnetic methods for breast cancer detection and a novel antenna design for microwave imaging,"** 2017.

[14] A. M. Abbosh, **"Directive antenna for ultrawideband medical imaging systems,"** *Int. J. Antennas Propag.*, vol. 2008, 2008, doi: 10.1155/2008/854012.

[15] I. Ünal, B. Türetken, and C. Canbay, **"Spherical Conformal Bow-Tie Antenna for Ultra-Wide Band Microwave Imaging of Breast Cancer Tumor.,"** *Appl. Comput. Electromagn. Soc. J.*, vol. 29, no. 2, pp. 124–133, 2008.

[16] R. Çalışkan, S. S. Gültekin, D. Uzer, and Ö. Dündar, **"A microstrip patch antenna design for breast cancer detection,"** *Procedia-Social Behav. Sci.*, 2015.

[17] X. Xiao and T. Kikkawa, **"Influence of the organism interface on the breast cancer detection by UWB,"** *Appl. Surf. Sci.*, vol. 255, no. 2, pp. 597–599, 2008.

[18] H. Zhang, R. Zhou, Z. Wu, H. Xin, and R. W. Ziolkowski, **"Designs of ultra wideband (UWB) printed elliptical monopole antennas with slots,"** *Microw. Opt. Technol. Lett.*, vol. 52, no. 2, pp. 466–471, 2010.

[19] H. Zhang, "**Microwave imaging for ultra-wideband antenna based cancer detection,"** The University of Edinburgh, South Bridge, Edinburgh, Scotland, 2014.

[20] C.-F. Tseng, C.-L. Huang, and C.-H. Hsu, **"Microstrip-fed monopole antenna with a shorted parasitic element for wideband application,"** *Prog. Electromagn. Res.*, vol. 7, pp. 115–125, 2009.

[21] A. R. Celik, M. B. Kurt, and S. Helhel, "**Design of an elliptical planar monopole antenna for using in radar-based and ultra-wideband microwave imaging system,"** *Int. Res. J. Eng. Technol.*, vol. 4, no. 11, pp. 1978–1983, 2017.

[22] C. A. Balanis, *Antennas Third Edition*. 2005.

[23] R. Garg, P. Bhartia, I. J. Bahl, and A. Ittipiboon, *Microstrip antenna design handbook*. Artech House Antennas and Propagation Library, 2001.

[24] G. Kumar and K. P. Ray, *Broadband microstrip antennas*. Artech house, 2003.

[25] D. M. Pozar and D. H. Schaubert, *Microwave Antennas:The Analysis and Design of Microstrip Antennas and Arrays*. 1995.

[26] G. Hill, **"A practical guide to the design of microstrip antenna arrays,"** *Microw. J.*, 2001.

[27] M. Shareef and M. V Krishnaraj, **"Lectotypification of" Garcinia imberti"** Bourd.(Clusiaceae)," *Taiwania*, vol. 60, no. 3, pp. 148–149, 2015.

[28] O. Hazila, S. A. Aljunid, F. Malek, and A. Sahadah, **"Performance comparison between rectangular and circular patch antenna array,"** 2010.

[29] M. S. R. M. Shah *et al.*, **"Design of 1× 2, 1× 4, and 2× 2 Dual Polarization Microstrip Array Antenna,"** 2008.

[30] K. R. Sipora, K. J. S. Lorraine, and D. V. Ratnam, **"Design of Inset-Fed Ceramic Patch Array Antenna for Pseudolite Based Positioning Applications,"** *Int. J. Innov. Res. Dev.*, vol. 3, no. 11, 2014.

[31] M. A. Matin and A. I. Sayeed, **"A design rule for inset-fed rectangular microstrip patch antenna,"** *WSEAS Trans. Commun.*, vol. 9, no. 1, 2010.

[32] J. R. James and P. S. Hall, **"Handbook of microstrip antennas,"** *Instution Eng. Technol. 2. Ed.*, p. 1350, 1998.

[33] C. S. T. M. Studio, **"URL http://www. cst. com/Content/Products/MWS,"** *Overview. aspx*. .

[34] V. Rajeshree, **"Design of array antenna for centric communication/Rajeshree Vejasegaran,"** University of Malaya Kuala Lumpur, 2017.

[35] A. Slimani, S. D. Bennani, A. El Alami, and M. Amellal, **"Gain and bandwidth enhancement of New Planar microstrip array antennas geometry for C band weather radar applications,"** *Int. J. Microw. Wirel. Technol.*, pp. 1139–1146, 2017.

[36] R. J. P. Douville and D. S. James, **"Experimental study of symmetric microstrip bends and their compensation,"** *IEEE Trans. Microw. Theory Tech.*, vol. 26, no. 3, pp. 175–182, 1978.

[37] E. Porter, **"Microwave breast tumor detection: Simulation and design of experiments with tissue phantoms,"** 2010.

[38] T. Sabapathy, M. F. Jamlos, R. B. Ahmad, M. Jusoh, M. I. Jais, and M. R. Kamarudin, **"Progress In Electromagnetics Research C, Vol. 30, 189–199, 2012,"** *Prog. Electromagn. Res.*, vol. 30, 2012.