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Nihal F. F. Areed
Prof. at Electronics and Communications Engineering Department, Faculty of Engineering, Mansoura University-, nahoolaf@mans.edu.eg

Hamdi Ahmed El Mikati
Professor, Electrical Engineering Department, Faculty of Engineering, Mansoura University, Mansoura, Egypt,

Laila T. Rakha
Laila Taher, Researcher at Department of Electronic and Communications, Faculty of Engineering, Mansoura University

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ORIGINAL STUDY

Breast Tissue Tumor Detection Using a Microstrip Patch Antenna With Defected Ground Structures

Laila Taher, Nihal F.F. Areed*, Hamdi A. Elmikati

Department of Electronics and Communications Engineering Department, Faculty of Engineering, Mansoura University, Mansoura, Egypt

Abstract

This work proposes a slotted microstrip patch antenna with an inset feed and Defect Ground Structure (DGS). The goal is to develop a broadband antenna with high gain and use it to detect tumors in breast tissue. The proposed antenna is constructed using Roger-RT/5880 (εr=2.2) as the substrate material for X-band applications with a resonant frequency of 10 GHz. The proposed design was simulated using the Finite Element Method (FEM). Bandwidth and gain results obtained were approximately 700 MHz and 8 dB; respectively. In addition, the position of the antenna relative to the breast phantom used was optimized to efficiently identify tumors with a minimum radius of 3 mm, taking into account specific safety aspects where the SAR values is less than 1.6 W/Kg for a 1g of cube-shaped tissue.

Keywords: Bandwidth, Breast tissue tumor, Defected ground structure, Gain, Microstrip patch antenna, Phantom breast model

1. Introduction

In light of the growth in breast cancer mortality over the past few decades, numerous techniques using breast phantoms have been investigated and tried in an effort to replicate the properties of genuine breast tissues (Fear et al., 2002). Previous research has shown that the tumor's permittivity is 10–20% higher than that of healthy tissues. Human body tissues can be divided into three groups based on their water content: tissues with a high water content that resemble malignant (tumor) tissues, tissues with a medium water content that resemble the skin and other transitional tissues, and tissues with a low water content that resemble normal tissues. Microwave tomographic imaging is being researched as a potential early breast cancer detection tool. The existence of breast cancer can be easily detected by evaluating dielectric permittivity profiles, as malignant tissues have a greater dielectric permittivity value than normal tissues, even at an early stage when treatment is still possible. When compared with traditional radiograph mammography, this is a benefit of the approach. Thus, early-stage breast cancer can be identified by microwave imaging (Lazebnik et al., 2005).

The ultimate finding and imaging performance are significantly influenced by the antennas. An antenna for one of these systems needs to be easy to integrate, small, have a straightforward geometric structure, have a wide bandwidth, and have a high gain (Balanis, 2016; Balanis, 2005; BYUNugraha et al., 2020). Microstrip patch antennas (MPAs) can meet these needs. It has a low profile, lightweight, low volume, planar configuration, and low fabrication cost, among other advantages. Defected ground structure (DGS) is commonly used to improve the performance of traditional MPAs between 10 dB bandwidth and gain. This feature has been used in the proposed design to improve the patch antenna's performance. Wide bandwidth, high gain, and efficiency

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* Corresponding author at: Department of Electronics and Communications Engineering, Faculty of Engineering, Mansoura University, Mansoura, Egypt.
E-mail address: nahoolaf@mans.edu.eg (N.F.F. Areed).

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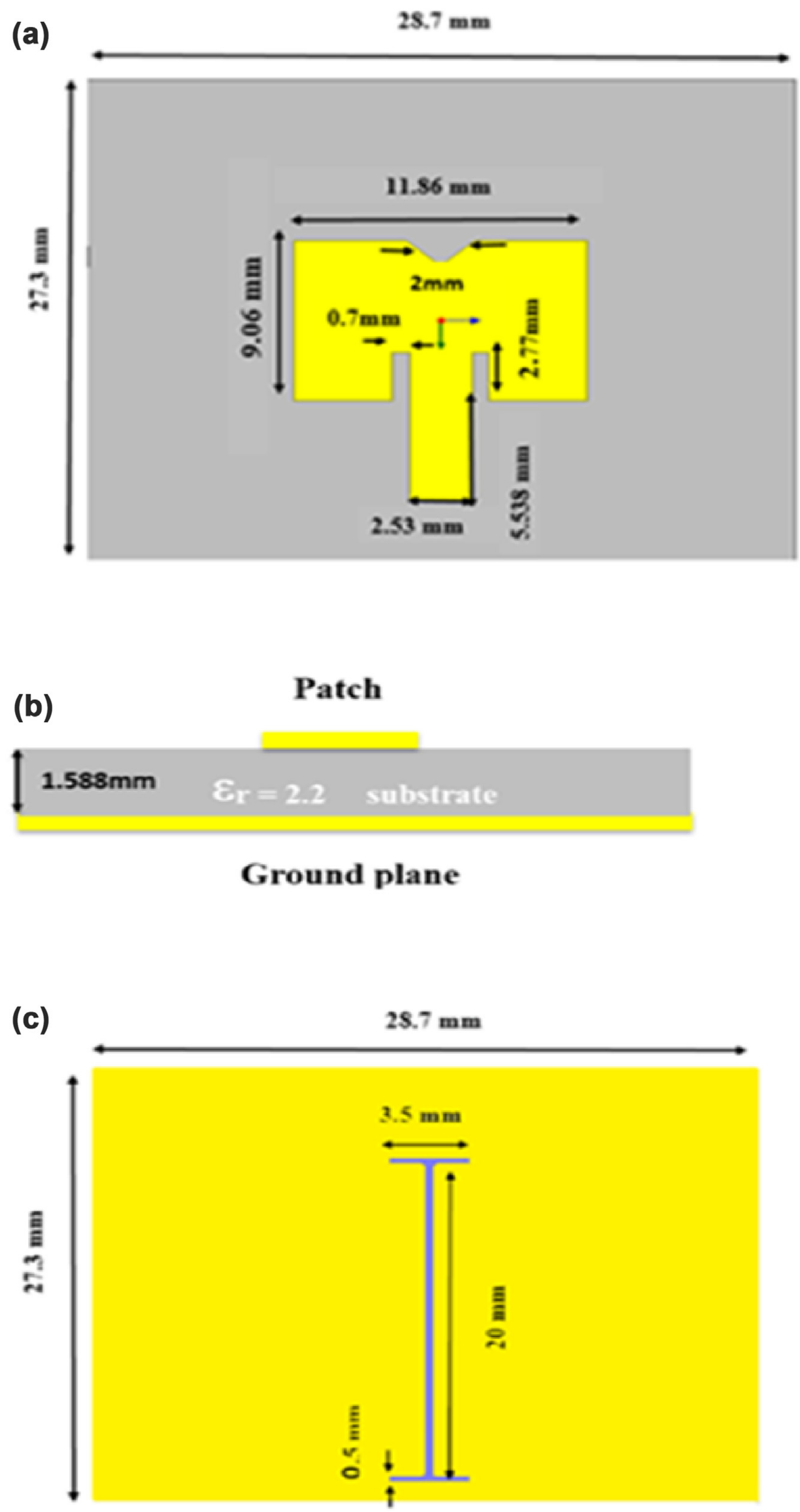

Fig. 1. The proposed antenna configuration: (a) top view, (b) side view, and (c) bottom view.

are all part of this improvement (Parbat, 2018; Okoro and Oborkhale, 2021). The proposed antenna design is tested in a phantom breast model by delivering signals to the breast model and receiving backscattered signals (Zhao et al., 2013; Ouerghi et al., 2017; Liu et al., 2012; Lazebnik et al., 2007a, 2007b). Microwave techniques to breast imaging have been presented as complementary methods for obtaining pictures related to the electromagnetic properties of breast tissues. It is expected that healthy tissues will differ significantly from one another, which will present difficulties for microwave signal measurement and image generation (Zastrow et al., 2008; Lazebnik et al., 2007c; Saleeb et al., 2021). In this paper, a slotted MPA with an inset feed and DGS is proposed and simulated. Roger-RT/5880 ($\varepsilon_r = 2.2$) is used as the substrate material for the considered antenna that is designed around 10 GHz. The proposed design has bandwidth and gain of about 700 MHz and 8 dB; respectively. The suggested antenna is used to identify breast tissue tumors of various radii while also taking into account the unique safety concerns; specific absorption rate (SAR) to be less than 1.6 W/kg for a 1 g of cube-shaped tissue.

2. Proposed design

The proposed MPA's top, side, and bottom views are seen in Fig. 1a–c. A patch constructed on a Rogers RT/Duroid 5880 (tm) substrate with a dielectric constant of 2.2 and a loss tangent of 0.009 is fed using the inset-fed approach, as illustrated in Fig. 1. The substrate is chosen to have dimensions of 27.3 and 28.7 mm. The substrate is 1.588-mm thick; 9.06 mm × 11.86 mm make up the patch's length and breadth, respectively. The rectangular patch antenna's design equation was used to obtain the dimension (Balanis, 2005, 2016). The ground plane and patch have been supplied with an I-shaped hole and a triangle-shaped hole, respectively, to tune the frequency around 10 GHz and increase performance. Further, a triangle-shaped hole with base of 2 mm has been etched on the top edge of the patch. The dimensions of etched holes have been selected after many trials to enhance the performance without affecting the operating frequency.

3. Simulation results and discussion

Using the finite element method, the performance of the suggested design has been calculated. Return loss and gain are the calculated metrics, as shown in Fig. 2a and b, respectively. It is obvious that the slotted MPA's return loss is −32 dB at 10 GHz; its bandwidth is 700 MHz; and its gain is 8 dB.

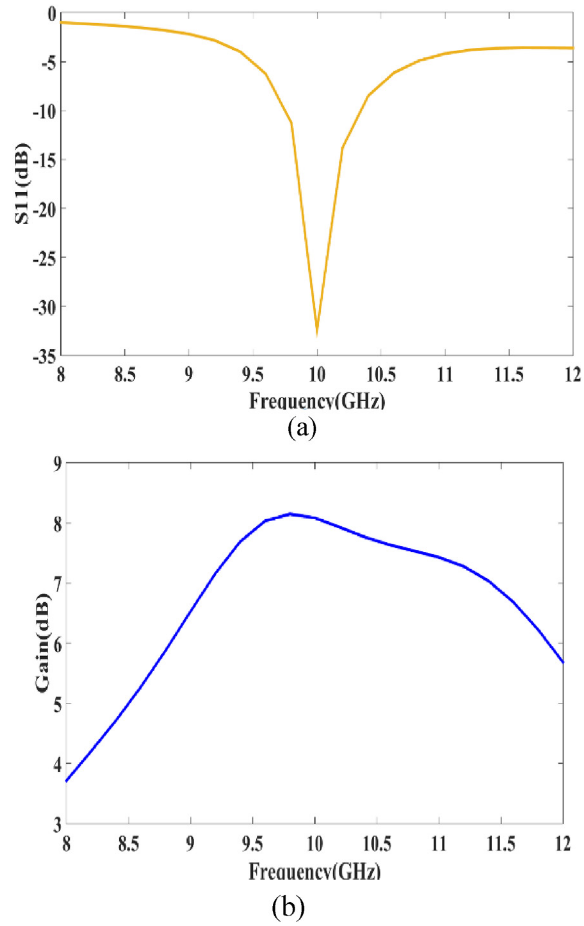

Fig. 2. (a) Return loss of proposed design and (b) gain.

Table 1 compares the suggested design in Fig. 1 with previously published equivalent designs in light of the most recent research. The table makes it abundantly evident that the suggested design with tuned dimensions offers higher gain and wider bandwidth than what has already been described (BYUNugraha et al., 2020; Parbat, 2018; Okoro and Oborkhale, 2021).

4. Detecting breast tumor with the proposed microstrip patch antennas

Blood, fat, and numerous other biological substances with varying permittivity and conductivity make up the biological tissue, which is a very

Table 1. The proposed antenna and previous researches at the X-band.

Tissues	Radius (mm)	Dielectric constant	Conductivity σ (S/m)
Skin	70	36	4
Fat	65	9	0.4
Fibroglandular	60	11	0.4
Tumor	2–5	50	5

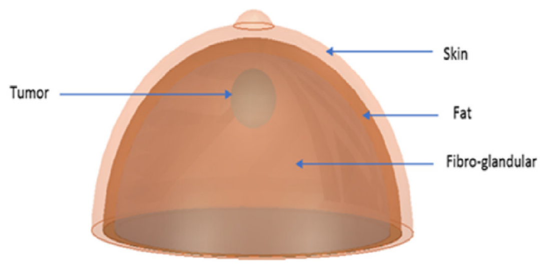

Fig. 3. Breast cancer phantom at 10 GHz (Zhao et al., 2013).

nonhomogeneous substance. The breast tumor phantom in Fig. 3 has three layers: skin, fat, and the fibroglandular tissue. The first layer is the skin; the second layer is the fat; and the third layer is the fibroglandular tissue. Table 2 provides an illustration of each layer's size, conductivity, and dielectric properties. The suggested MPA is placed in front of the breast in order to detect cancers, and the return loss for antenna using breast with and without tumors of 5 mm radius will be calculated. The best distance between the MPA and the breast is examined and chosen. As depicted in Fig. 4, S11 is calculated using a 1, 2, and 3 mm spacing. The figure shows how tumors can be easily identified with either 1 or 3 mm spacing, depending on whether the tumor caused the patch's resonance to move to higher frequencies.

The safety of microwave-based breast imaging equipment must be safeguarded by a thorough examination of SAR because even a brief exposure to emission could constitute a major health risk. SAR is used to determine how much electromagnetic radiation is gradually accumulated in the human body tissue. Watts per kilogram of body mass are the most widely used units. When evaluated across the volume containing a mass of 1 g of tissue that is absorbing the most signal, the SAR level of a phone must be at or below 1.6 W/kg. The Federal Communications Commission (FCC) set forth this condition. The following relation is used to calculate the SAR (Saleeb et al., 2021):

Table 2. Dimensions and dielectric characteristics of the breast phantom with tumor at 10 GHz (Zhao et al., 2013).

Publication	Fr (GHz)	BW (MHz)	Gain dB
Putri et al. (BYUNugraha et al., 2020)	10	410	10.94
Parbat et al. (Parbat, 2018)	11.5	470	6
Okoro and Oborkhale (Okoro and Oborkhale, 2021)	10	226.2	6.58
This work	10	700	8

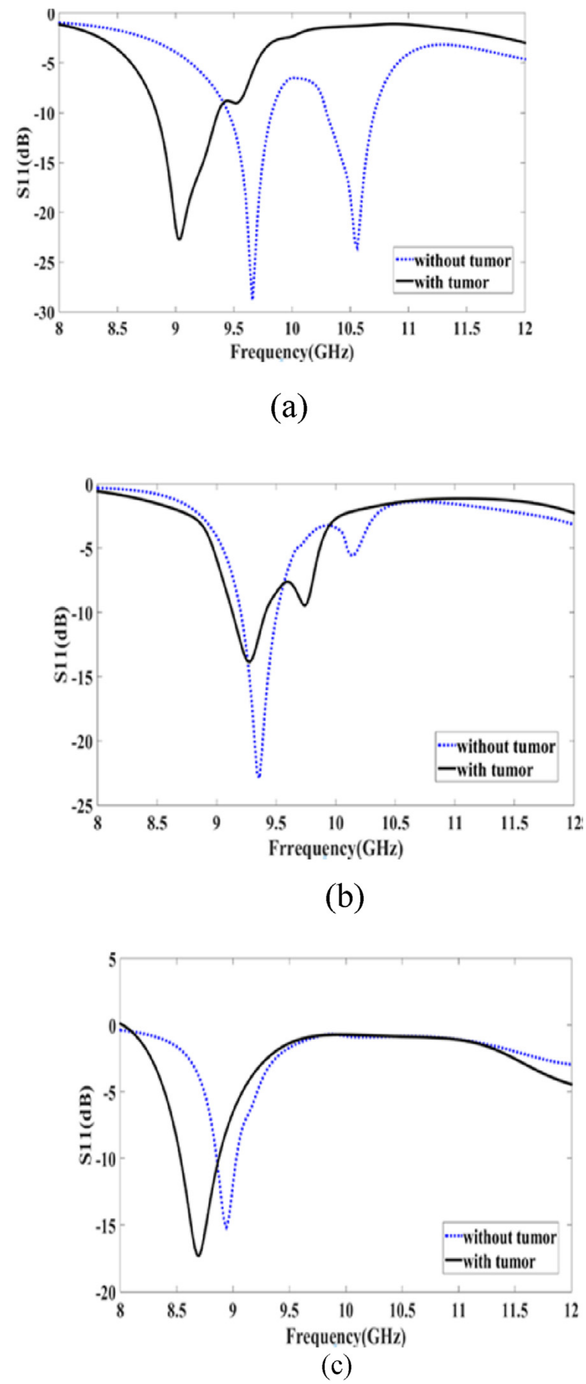

Fig. 4. Return loss of the proposed MPA held in front of breast phantom with spacing: (a) 1 mm, (b) 2 mm, and (c) 3 mm. MPA, microstrip patch antennas.

$$\mathrm{SAR} = \frac{\sigma}{\rho}[E]^2 = \frac{J^2}{\rho\sigma}[W/kg] \quad (1)$$

where E is the rms value of the electric field strength in the tissue (V/m); J is the current density (A/m); σ is the conductivity of the head tissue (S/m); and ρ is the density of head tissues (kg/m^3).

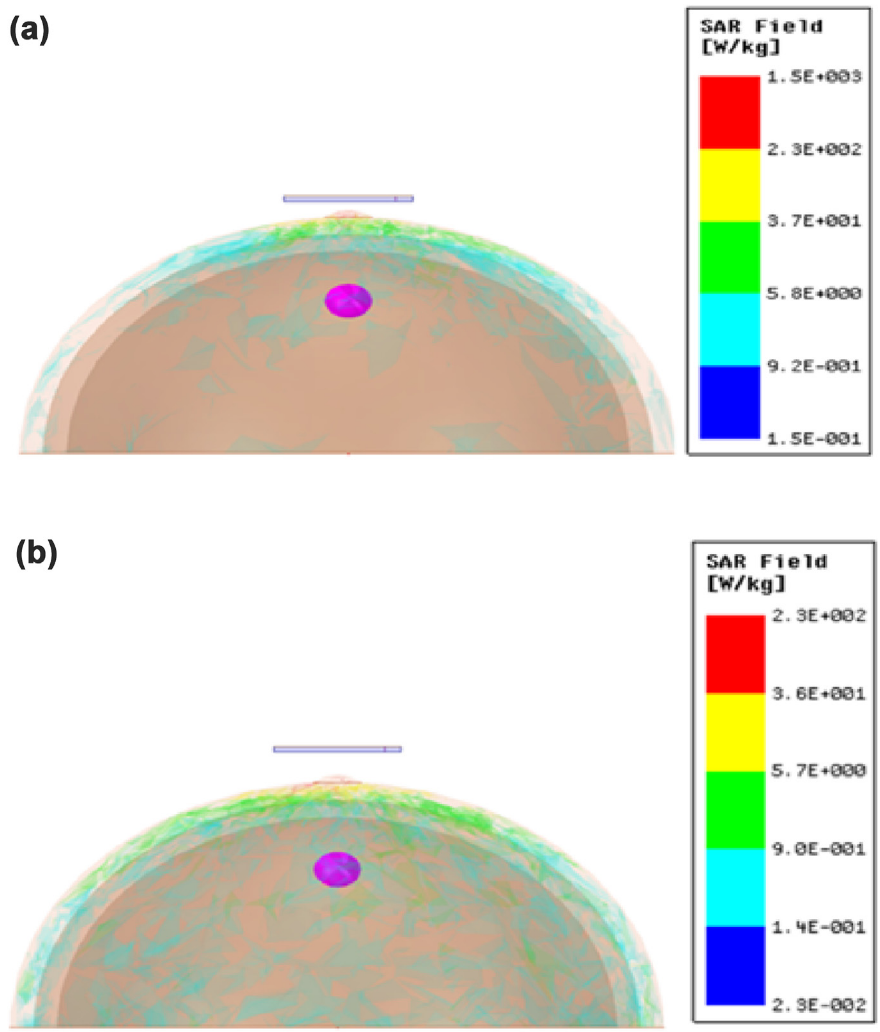

Fig. 5. SAR at (a) d = 1 mm and (b) d = 3 mm at 10 GHz.

Fig. 5 depicts the calculated SAR absorbed by a breast with a 5 mm tumor as a result of radiation from the suggested antenna set in front of the breast phantom at 1 and 3 mm spacing, respectively.

The graphic shows that SAR reads 1.7 kg/W at 1 mm pacing and 0.23 kg/W at 3 mm spacing.

Therefore, the proposed antenna may detect cancers effectively and without posing a severe health danger when it is held 3 mm from the breast.

The return loss curves of the suggested antennas held at 3 mm in front of the breast with various tumor radii are calculated as shown in Fig. 6 to study the smallest tumor dimensions that the proposed antenna can detect. The image makes it clear that tumors with a diameter of 4 and 3 mm can be recognized with ease in locations where the resonance of the antenna is obviously pushed toward higher frequencies. This indicates that the proposed antenna can identify tumors with a minimum size of roughly 3 mm.

Once more, Fig. 7 displays the SAR estimates for tumors with diameters of 3 and 4 mm. It is possible to demonstrate that the calculated SAR values for a 1 g cube-shaped tissue are less than 1.6 W/kg.

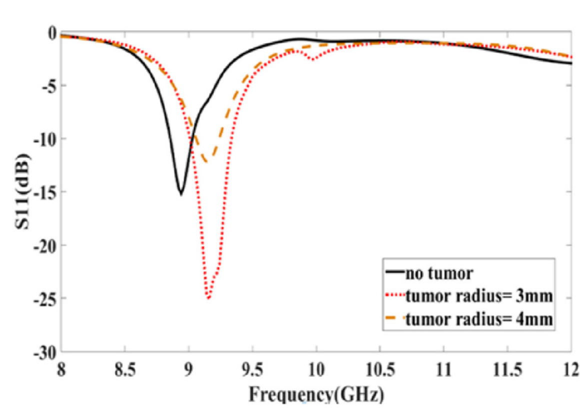

Fig. 6. Return coefficient of different sizes of tumor.

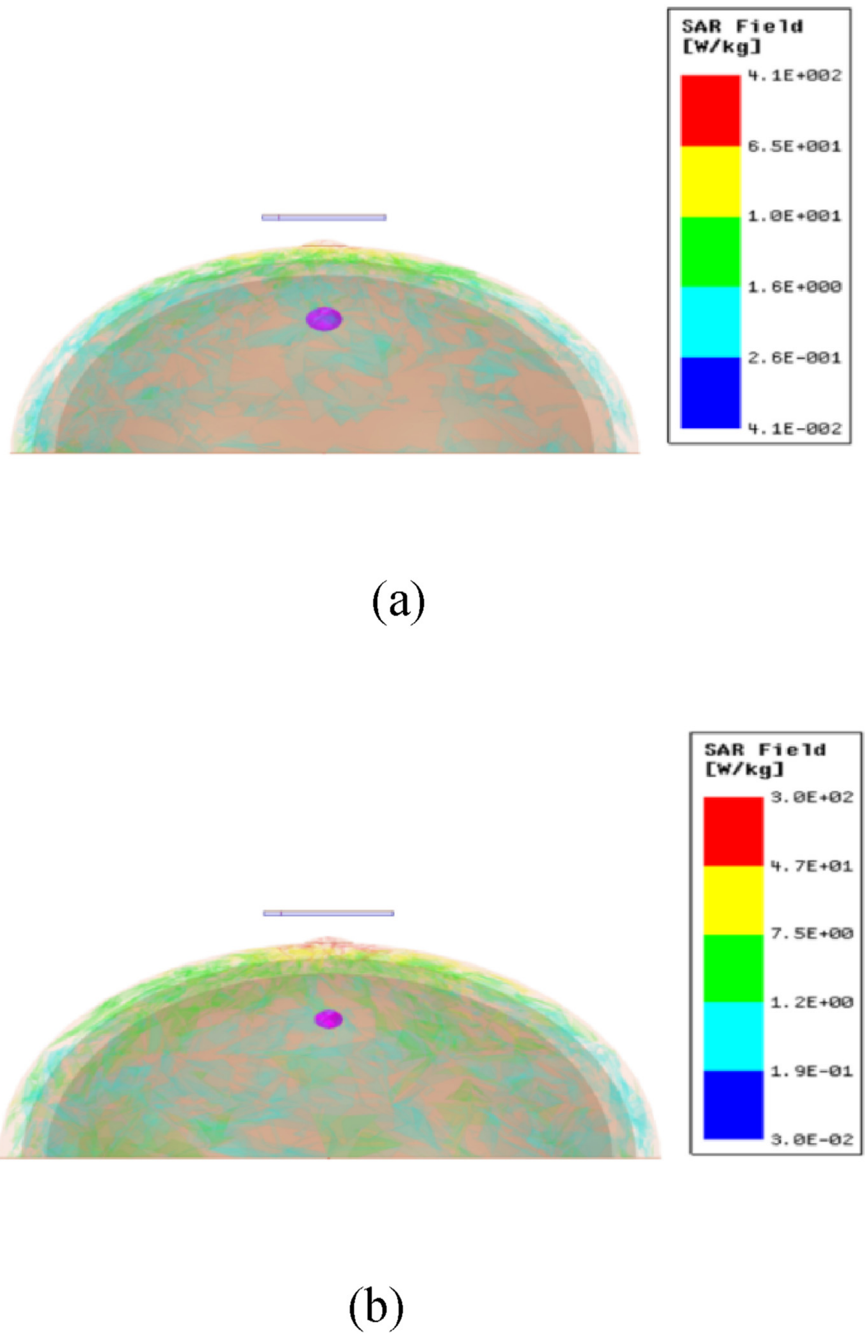

Fig. 7. SAR of different sizes of tumor: (a) tumor radius = 4 mm and (b)tumor radius = 3 mm around 10 GHz.

5. Conclusion

This study presents and simulates a high gain, wideband rectangular patch antenna. A Rogers-RT/5880 substrate with a loss tangent of 0.009, a thickness of 1.588 mm, and a dielectric constant of 2.2 is used. The proposed antenna is placed on top of a DGS and uses the microstrip line feed. The dimensions of the proposed design are optimized at around 10 GHz, resulting in a bandwidth of 700 MHz and a gain of 8 dB. The suggested antenna has been successfully used to diagnose breast tumors based on an analysis of return coefficient and specific absorption rate SAR. Based on a study of matching characteristics and SAR, the proposed antenna has been successfully used to safely identify breast tumor with a minimum radius of 3 mm.

Conflict of interest

There are no conflicts of interest.

Author contribution

Authors contribution: Laila Taher: conceptualization. Nihal F.F. Areed: methodology. Laila Taher: software, formal analysis. Laila Taher and Nihal F.F. Areed: investigation. Laila Taher and Nihal F.F. Areed: writing − original draft preparation. Laila Taher and Nihal F.F. Areed: writing − review and editing. Laila Taher and Nihal F.F. Areed and Hamdi A. Elmikati: visualization. Laila Taher, Nihal F.F. Areed, and Hamdi A. Elmikati: supervision.

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