UWB antenna with circular patch for early breast cancer detection

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Abstract

Breast cancer is the most common cancer in women. It has the highest incidence rate and the highest mortality rate. In recent years, the incidence of breast cancer has become more and more important, it is becoming the first tumor killer for women around the world. Early diagnosis is the most important parameter for detecting cancerous tissue to prevent serious consequences. In this electronic paper, we present a new design of an ultra-wide-band circular microstrip patch antenna operating in the recommended FCC band ([3.1 GHz - 10.6 GHz]) for the detection of breast tumors. The antenna is printed on an FR4 epoxy substrate with a dielectric permittivity ϵ_r = 4.4 and loss tangent tan δ = 0.02. The results obtained are largely satisfying and prove that the proposed antenna is a candidate for biomedical applications.

Keywords: *breast cancer, microwave imaging detection, specific absorption rate, ultra wideband antenna*

1. Introduction

Mammary cancer is one of the most common malignant tumors in women that usually occurs in breast glandular epithelial tissue, which seriously affects women's physical and mental health and even life-threatening [1-3]. The incidence rate is 7-10% of all kinds of malignant tumors in the body. This is the second major problem of women's health after uterine cancer. Its causes are often related to heredity [4].The age distribution of the disease varies in the east and west countries. Breast cancer begins to appear around the age of 20 and maintains a rapid upward trend before the menopause, 45–50 years old. The incidence rate increases by about 1 for every 10–20 years of age. The rise after the menopause period is relatively slow. Breast cancer is rare in men, and only about 1-2 % of breast patients are male [5]. According to the annual report of breast cancer incidence and mortality in China, the incidence rate of female breast cancer is lower at the age of 0–24 years old, gradually rising after 25 years old, reaching the peak in the 50–54 age group, and gradually decreasing after 55 years old. The incidence of breast cancer in Chinese women is still low [6, 7].

Until now, the cause of breast cancer is not completely mastered. The study revealed a certain regularity in the incidence of breast cancer. In recent years, the discovery of dense breast glands has become a risk factor for breast cancer. Some people call breast cancer a female killer. Every year, many women lose their lives because they neglect breast cancer. For breast examination, There are several diagnostic techniques. Among these techniques there is the imaging test. A mammogram is an X-ray that is commonly used for initial screening of breast cancer. It produces images that can help detect any lumps or abnormalities. Suspicious results can be further diagnosed. However, mammograms sometimes find a suspicious area, not cancer. This can lead to unnecessary stress and sometimes intervention. So, the ultrasounds can help distinguish between solid and liquid substances, and MRI examines a patient with a dye to determine the extent of cancer spread [8-10].

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Other technique consists of a surgical sample of tissue samples for laboratory analysis. This can indicate whether the cell is cancerous and sometimes determine which cancer is involved, including if the cancer is sensitive to hormones [11]. The diagnosis also includes the possibility of determining the size of the tumor, how far it has spread, whether it is invasive or noninvasive, whether it is metastatic or spreads to other parts of the body. A better examination will help determine the best treatment options. The major disadvantage of the techniques mentioned above is the very high cost of the implementation of its technological means. For this purpose, patch antennas are an innovative alternative in the medical field to reduce the cost and produce localized images of tumors [12-14].

This document presents an ultra wideband circular patch antenna that meets the standards required by the Federal Communications Commission (FCC) in terms of bandwidth for the detection of breast tumors [15, 16]. The principle is to detect tumors in the breast using the microwave signals. Breast tumors have very distinct electrical properties (dielectric permittivity and conductivity are very high), which makes it possible to detect them by analyzing the emitted and reflected signals. The quantity of the signal absorbed by a breast with tumors is greater than that absorbed by normal breast tissue. The following sections will detail the models used and the results obtained.

2. Models Design Process

2.1. UWB Antenna Design

The structure of the ultra wideband antenna used for the detection of breast cancer is illustrated in Figure 1. The chosen radiating configuration is a circular patch width 50 printed on an FR-4 substrate with relative permittivity ϵ_r=4.4, loss tangent δ=0.02 and a thickness of Hs =1.6 mm. The final dimensions of the optimized antenna using the finite element method are listed in Table 1.

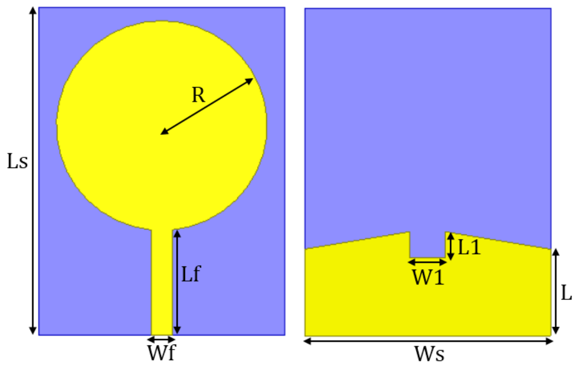


Figure 1. Geometry of the proposed antenna, left side: top view, right side: bottom view

Table 1. Optimized Dimensions of the Proposed Antenna in mm

Parameters	Value	Parameters	Value
W_s	28	R	12
L_s	37.5	L	9.9
W_f	2.5	W_1	4
L_f	12	L_1	3

3. Antenna Performance

To validate the performance of the proposed antenna, we used another numerical solver based on the Finite Integration Technique (FIT) to give more reliability to our design. The Table 2 summarizes the results obtained by the two solvers. The variation of the gain as a function of the frequency is illustrated in Figure 3. From this figure, we notice a very good gain obtained over the entire frequency band. We have a maximum gain of 8.28 dB at 2.83 GHz and a gain greater than 3.83 dB over the entire frequency band of [2.83 - 10.42] GHz. The gain is very satisfactory for biomedical applications. Table 3 compares the performance of the proposed antenna with some recently developed UWB antennas. The proposed antenna has the advantages of wider impedance bandwidth, low cost, compact size, and good gain performance.

Table 2. Comparison Between FIT and MEF Solvers

Solver methods	Bandwidth f_1-f_2 [GHz]	Bandwidth Value [GHz]	Return loss max [dB]
FIT	2.59 - 10.32	7.73	-37.55
FEM	2.83 - 10.42	7.58	-43.34

Figure 2 illustrates the reflection coefficient obtained by the two solvers (Finite element method FEM and Finite Integration Technique FIT). We note a good agreement between the simulated results. There is a small gap between the two curves due mainly to the mesh taken by the two techniques.

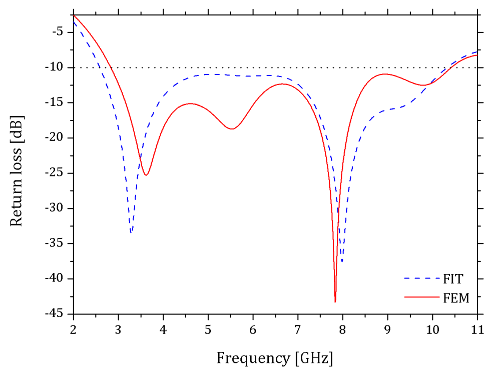


Figure 2. Return loss vs frequency calculated by FIT and FEM methods

Table 3. Comparison of Previous Sesigns with the Proposed Antenna

UWB Antenna	Substrate ϵ_r	Size $[mm^2]$	Bandwidth $[Ghz]$	Gain $[dB]$
[3]	4.4	20×35	3-12	5.2
[17]	4.5	36.5×40.5	3.6-8.4	Not reported
[18]	2.4	75×75	1.15-4.4	2-8
This work	4.4	28×37.5	2.83-10.42	3.83-8.28

3.1. Breast and Tumors Model

Each breast of a woman contains a mammary gland that consists of fifteen to twenty compartments separated by fatty tissue and tissue that contains vessels, fibers, and fat. The compartments of the mammary gland consist of lobules and canals. The role of lobules is to produce milk during breastfeeding. The canals carry the milk to the nipple. In order to validate the detection method proposed in this paper, a model represent ing the main tissues of the breast is needed. From recently published works, researchers have proposed several three-dimensional models [19-21]. A 3D perspective representation of the adopted model is shown in Figure 4.

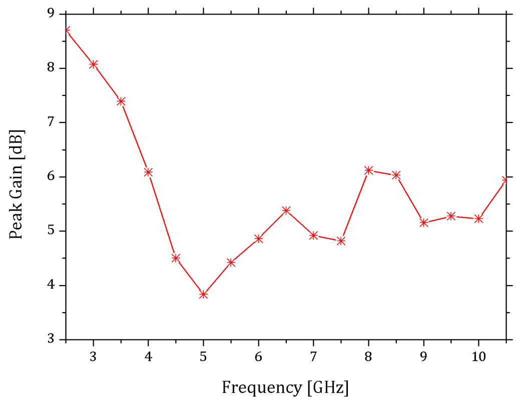


Figure 3. Peak gain of the proposed antenna vs frequency

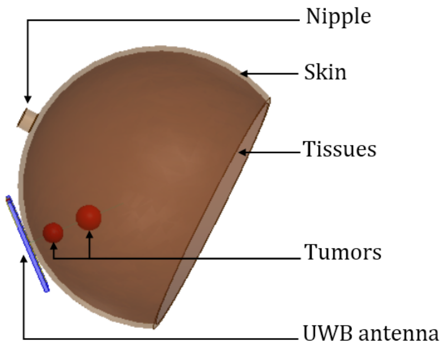


Figure 4. Breast model with 2 tumors

The breast model considered in this work is a hemispherical shape of 55 mm radius modeling heterogeneous breast tissue. It contains a layer of skin, a layer of breast tissues and tumors, and it illuminated by an ultra wide-band patch antenna at different frequencies. To simulate the presence of early tumors, we took three spheres with a radius of 3 mm, 4 mm, and 5 mm. Table 4 presents the dielectric properties of the biological layers that have been introduced into our model where ϵ_r is the dielectric permittivity and σ is the conductivity [22].

3.2. Specific Absorption Rate / Power Absorption

The Specific Absorption Rate (SAR) is defined as the time derivative of the quantity of energy carried by radio-frequency waves (dW) absorbed by a mass (dm) of a biomedical tissue, especially the human body contained within a volume (dV) having a given density (ρ) [20, 23-25]

Table 4. Dielectric Properties of the Proposed Breast Model

	Dielectric permittivity ϵ_r	Conductivity [S/m] σ
Skin	39	1.1
Tissues	4.49	0.59
Tumor	50	4

the unit of SAR is the watt per kilogram (W/kg). It is expressed as:

$$SAR = \frac{d}{dt}\left(\frac{dW}{dm}\right) = \frac{d}{dt}\left(\frac{dW}{\rho dv}\right) \tag{1}$$

the following equation explains the total absorbed power deduced from (1).

$$P_{abs} = SAR_{total} \times Tissue\ mass \tag{2}$$

the SAR quantity is related to the internal E-field and J density by:

$$SAR = \sigma\frac{E^2}{\rho} = \frac{J^2}{\sigma\rho} \tag{3}$$

In which:
- E is the electric field (V/m) and J is the current density (A/m^2) in the tissue;
- ρ is the mass density (kg/m^3) and σ is the electrical conductivity of tissue (S /m).

In the United States, the Federal Communications Commission (FCC) requires the SAR level to be less than 1.6 W/kg for 1 gram of tissue. While in the European Union, the SAR limit is 4 W/kg, which the average relates to 10 grams of tissue. For exposure of the entire human body, the threshold is 0.08 W/kg, which the average refers to the whole body [26].

4. Numerical Results and Discussion

In the literature, the size of the tumor is between about 2 mm and 15 mm or more [27]. We use spherical tumors with 3mm, 4mm and 5mm radii placed at different positions to analyze antenna sensing capabilities and the effect of tumor size. The proposed model consists of a 55 mm radius hemisphere. It is illustrated in Figure 4.

4.1. Distance Detection Effect on SAR

Figure 5 shows the numerical simulation distribution of SAR in the mammary tissue as a function of the distance between the UWB antenna and the breast containing a tumor size of 3 mm placed at a distance of 12 mm from the antenna. The numerical simulation shows that the SAR value is very significant when the distance is equal to 0 mm. The maximum value reaches 52,126553 W/Kg at 6 GHz frequency. However, at a distance of 2 mm, the maximum SAR value with a tumor of 3 mm is 1.504771 W/kg at 5 GHz. Taking into account the limitations imposed in section 3.2, we take the distance of 2 mm as the detection distance.

4.2. Tumor Size Effect on SAR

To analyze the effect of tumor size on SAR distribution, we introduced three tumors with the following radii: 3 mm, 4 mm, and 5 mm. Numerical calculations demonstrate that tumor size is a potential parameter to influence the distribution of SAR values. From Figure 6, the effect of tumor size can be classified into three phases:

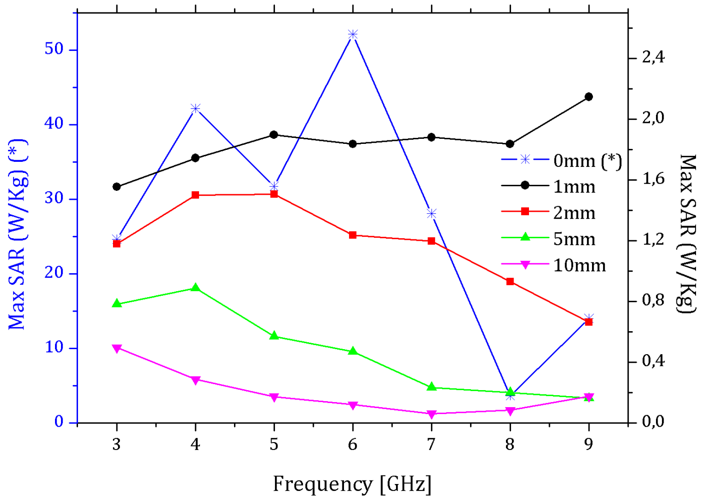


Figure 5. Numerical simulation SAR in the mammary tissue vs frequency at different distance between the UWB antenna and the breast. [(*) see left y-axis]

- Phase 1: between 3 and 5 GHz, as long as the tumor size increases the SAR increases significantly.
- Phase 2: by increasing the frequency between 5 and 7 GHz, the SAR value starts to decrease rapidly.
- Phase 3: In the [7-9] GHz band, the size of the tumor has practically no effect on the SAR value.

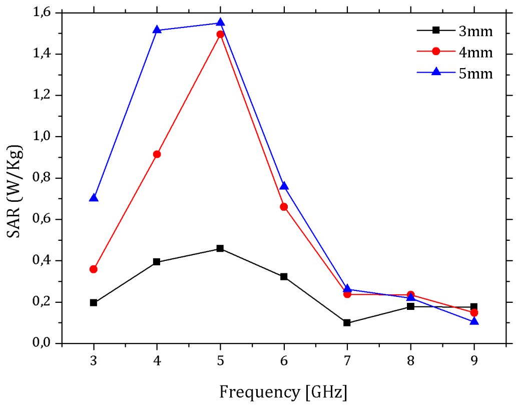
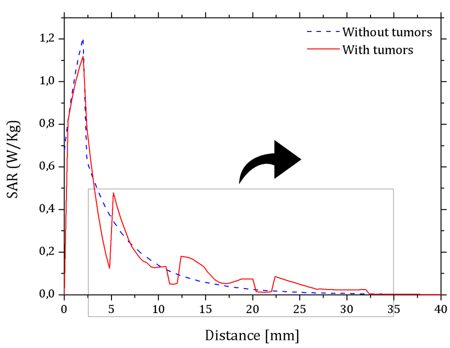


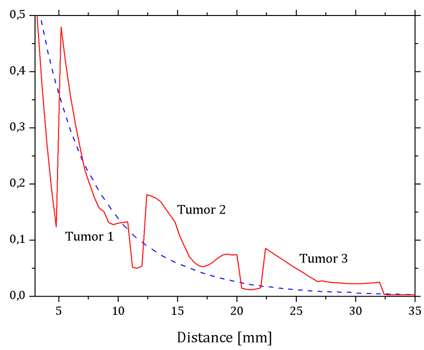
Figure 6. Numerical simulation SAR in the mammary tissue vs frequency by varying the size of the tumor

4.3. Breast Cancer Detection

This paragraph describes the method detection mainly applied to the analysis of the presence of tumors in breast tissues. The results of our technique are very satisfactory and they are illustrated in Figure 7 and summarized in the Table 5. Figure 7 shows an example of detection of three tumors of radius 3 mm, 4 mm and 5 mm placed respectively at a distance of 8 mm, 16 mm and 27 mm from the ultra wideband antenna which resonates at a frequency of 3.62 GHz. However, Table 5 presents the different configurations of the tumors studied and analyzed. It summarizes the positions of the first and last detected point of the various tumors of 3 mm, 4 mm and 5 mm placed inside the breast tissues. We deduce that microstrip technology is efficient for detecting breast tumors and has the advantage that is less expensive compared to existing screening systems around the world.



(a)



(b)

Figure 7. SAR distribution for 3 tumors at 3.62 GHz, (a) zoom out, (b) zoom in

Table 5. Different Configurations of the Tumors Studied

Tumors configuration		I	II	III	IV	V	VI	VII
Tumor actual radius [mm]	Tumor 1	3	-	-	3	3	-	3
	Tumor 2	-	4	-	4	-	4	4
	Tumor 3	-	-	5	-	5	5	5
Tumor actual position [mm]	Tumor 1	10	-	-	13	13	-	18
	Tumor 2	-	10	-	21	-	8	8
	Tumor 3	-	-	10	-	24	20	29
Position of the first point of the detected tumor [mm]	Tumor 1	6.8	-	-	10	10	-	14.8
	Tumor 2	-	6	-	16.8	-	4	4
	Tumor 3	-	-	4.8	-	18.8	14.8	23.6
Position of the last point of the detected tumor [mm]	Tumor 1	13.2	-	-	16.4	16	-	21.2
	Tumor 2	-	14.4	-	25.2	-	12.4	12.4
	Tumor 3	-	-	15.2	-	29.2	25.2	34.4

5. Conclusion

In this manuscript, a new miniaturized UWB microstrip antenna, compliant with the FCC standard, has been designed, simulated and analyzed. The recorded numerical results have generally shown better performance compared to conventional antennas already designed and published. The characteristics of the proposed antenna are optimized by the finite elements method (FEM) by a parametric study of the different parameters. This project has several advantages: small size, simple and compact structure, ease of manufacture and wider bandwidth. All these advantages make this antenna a candidate solution for biomedical applications especially medical imaging to detect breast cancer.

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