

# Hyperthermia for Breast Cancer Treatment Using Slotted Circular Patch Antenna

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## Abstract

The primary intent of this paper is to investigate the potential of using a slotted circular patch antenna at 2.45 GHz for breast tumor hyperthermia treatment. A cancer treatment model consisting of a microstrip patch antenna and breast phantom comprising tumor is designed and simulated in CST Studio Suite 2018. The radiation properties of the proposed antenna attain 3 dB beam width of 74.1° and 70.5° for the E-Plane and the H-plane, respectively. The breast phantom is exposed to the designed antenna radiation for 10 minutes, leading to raise the breast phantom temperature by 8.5°C and 11.4°C once the antenna pumped power is 1.5 and 2 watt, respectively. By considering 10 minutes as an exposure time, the breast temperature as a function of the applied antenna power is studied and compared with previous published results.

# **Keywords**

Hyperthermia Treatment, Breast Cancer, Microstrip Antenna Design

# **1. Introduction**

Hyperthermia is extremely exploited to acquire a therapeutic level of the tumor through increasing its temperature at which the malignant tissues are heat-dependent or destroyed as a result of the increased local temperature above  $42^{\circ}C$  [1]. The heating is an effective technique to enhance the blood flow rate inside the tumors as the oxygenation is inherently low [2]. The hyperthermia has been considered the effective cancer therapy compared to the chemotherapy (*i.e.*, chemical toxins) and the X-ray (*i.e.*, ionizing radiation) [3]. In principal, thermal conduction, ultrasound and electromagnetic (EM) are different heating techniques which have been explored for hyperthermia treatment purposes [4]. Among these techniques, EM applicators play a significant role in medical

treatments, mainly within the breast cancer treatment process [5]. The EM applicators are divided into two different types, external and interstitial applicators. The external applicators are placed on the body surface where the tumors are located nearby while the interstitial ones are inserted inside the body at the tumor position.

In general, hyperthermia treatment comes in three different categories depending on the tumor position, namely whole body hyperthermia, regional hyperthermia and local hyperthermia [6]. The microwave hyperthermia treatment, as a promising approach, for breast tumor is presented in recently published studies [7] [8]. Antennas with different shapes were employed for temperature increase purposes [9] [10] [11]. However, the feed method and the shape of this antenna are more complex.

In the current work, the proposed antenna originated with a slotted circular patch shape. The antenna is designed and simulated, alongside breast phantom involving tumor using EM thermal co-simulation technique. The current antenna maintains a decent performance in terms of the exposure time, temperature evaluation and the input power when compared to the aforementioned antennas. The ultimate goal of the work is to realize efficient and high gain slotted circular antenna array for hyperthermia breast tumor therapy system, while the investigation here is to study the design of a single slotted circular antenna (a scaled version) in the first instance.

#### 2. Patch Antenna Design

This section purpose is to design a slotted circular patch antenna at the industrial, scientific and medical (ISM) radio band. The ISM band denotes a group of the radio spectrum, the most exploited frequencies are 0.434 GHz and 2.45 GHz. To design a microstrip patch antenna, three key factors should be carefully specified. These elements are the frequency of operation, the height of substrate and the dielectric constant of substrate. In this paper, the functioning frequency is selected to be 2.45 GHz fitting a wide range of medical applications such as the breast cancer detection and treatment. For medical application purposes, it is important that the employed antenna is not massive. Therefore, the selected height is 1.57 mm and the dielectric material of the substrate is Duroid 5880 with 2.2 dielectric constant.

The final layout of the centered slotted circular antenna is shown in **Figure 1**. The optimum dimension of the circular patch and the centered slot are 22.9 mm and 1 mm, respectively. The length of the feed line is 24 mm while its width is 0.7 mm. The match line has a length and width of 15 mm and 4.8 mm, respectively. The selected substrate is square in dimension with 100 mm<sup>2</sup> as similar to the metallic ground plane. To match the applied power, the height and the width of wave port are carefully selected. To ensure the radiation cannot be reflected back, the air box length is adjustable.

The return loss performance (S11) is shown in Figure 2. The S11 is the main



Figure 1. The structure of the slotted circular antenna.



Figure 2. The return loss performance.

parameter to inspect the power reflection of the antenna. It can be seen from **Figure 2** that the return loss shows a decent performance at the operating frequency (2.45 GHz) with better than -20 dB. This indicates that the incident power is efficiently transferred to the metallic circular patch, in turn, to the breast phantom afterward. It is also obvious that the bandwidth at the operating frequency is around 32 MHz.

The radiation patterns in the E-plane and H-plane of the 2.45 GHz antenna are shown in **Figure 3** and **Figure 4**. These planes are also known as the Azimuth plane and Elevation plane, respectively. It can be seen that the antenna has a 3 dB beam width with 74.1° at the azimuth plane whereas 70.5° at the elevation plane. It is noticeable from these radiation patterns that the Gain is above 7.5 dB presenting individually in a 3D pattern in **Figure 5**.

#### 3. Breast Cancer Hyperthermia Treatment

The current section presents the main goal of this work. The proposed model for the breast cancer treatment, using the radiation properties of the designed antenna in the previous section, is introduced. In principle, the proposed circular antenna emits Radio Frequency (RF) signals, as non-ionizing heating source, towards the modelled breast phantom where the breast tissues receive and absorb the incident antenna power. The highest value of the applied power is controlled and individual focused at the tumor position, preserving the healthy tissues absorbed power-free.

There is a linear relationship between the emitted RF signals and the encouraged temperature distribution inside the breast phantom. Subsequently, this induced temperature can be exploited in breast cancer hyperthermia therapy. A simple cone is used to create the 3D breast phantom at which the lower radius is 0 mm and the upper radius is 200 mm, while the height is 130 mm. The breast





Figure 3. Radiation pattern in E-Plane/Azimuth plane.



Farfield Gain Abs (Phi=90)

Figure 4. Radiation pattern in H-Plane/ Elevation plane.

phantom is placed 70 mm distant from the designed microstrip antenna. Likewise, a sphere with 20 mm diameter representing the inserted tumor inside the breast phantom is designed. **Figure 6** shows the structure, which is simulated and its prospective results are discussed in the following section.

## 4. Results and Discussion

The electrical and thermal properties of materials used to create the breast phantom and the tumor are illustrated in **Table 1**. The breast consists of a set of tissues, but for investigation purpose, the breast tissues are averaged as a single tissue at 2.45 GHz.

By considering  $37^{\circ}$ C of the normal body temperature, the induced energy of the antenna is applied to the breast phantom over a 10 minutes' exposure time and with input power of 0.5 W. Figure 7 shows a maximum temperature of



Figure 5. 3D-Gain radiation pattern.



Figure 6. The proposed model configuration.

39.8°C, which is insufficient for hyperthermia treatment.

In order to obtain the required temperature (*i.e.*, above 42°C), the antenna input power should be scaled as shown in **Figures 8-10**. It is clear that there is a linear proportional relationship between the applied power and the temperature inside the breast phantom. As a result, the input power of 1.5 W or 2 W provide an increasing in terms of the temperature to be above 8°C and 11°C in respective, which are appropriate for hyperthermia treatment when the exposure time is set to 10 minutes. **Table 2** demonstrates a comparison of the current results with respect to previous published results, at which the current results are compromise in terms of the exposure time and the input power of the antenna.

Tissue name	Permittivity (F/m)	Electrical Conductivity (S/m)	Density (Kg/m³)	Heat Capacity (KJ/K/kg)	Thermal Conductivity (W/K/m)
Tumor	50	2.1	1041	3.5	0.5
Breast	9	0.4	1058	3.639	0.42

Table 1. The average electrical and thermal properties of the breast at 2.45 GHz.



Figure 7. The heat distribution at 0.5 W.



Figure 8. The heat distribution at 1 W.



**Figure 9.** The heat distribution at 1.5W.



Figure 10. The heat distribution at 2 W.

Table 2. A comparison	n with othe	r published	results.
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Applied Power (Watt)	Exposure time (Minutes)	Operating Frequency (GHz)	Increased Temperature (°C)	Reference
1	8.65	1.6	3	[9]
45	30	4.2	6	[10]
50	3	0.434	12	[11]
1.5	10	2.45	8.5	Current Paper
2	10	2.45	11.4	Current Paper

# **5.** Conclusion

The potential of using a slotted circular patch antenna at 2.45 GHz for breast tumor hyperthermia treatment was investigated in this paper. The steps to fabricate and measure the proposed antenna to validate the current simulated results are taken into consideration through the next phase, where the ultimate goal to realize efficient and high gain slotted circular antenna array.

## **Conflicts of Interest**

The authors declare no conflicts of interest regarding the publication of this paper.

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