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# Pencil Beam Grid Antenna Array for Hyperthermia Breast Cancer Treatment System

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## Abstract

In this paper, efficient, high gain and pencil beam grid antenna array is proposed for hyperthermia breast cancer therapy system. The proposed antenna bandwidth extends from 4.8 GHz to 4.9 GHz at resonant frequency of 4.86 GHz. This frequency band has been reported for the breast cancer hyperthermia therapy. The grid long and short sides are responsible for the undesired cross-polarized radiation and desired copolarized radiation, respectively. The unsuitability of the conventional grid antenna array is ensured by investigating its radiation properties. The proposed grid antenna array short side width is varied and its long side width is kept wide as possible to enhance the radiation properties and to reduce the losses. Also, a reflector has been used for gain enhancement purpose. The proposed grid antenna array achieves side lobe level and 3 dB beam width of −27.9 dB and 25.9˚ for the E-plane and −27.9 dB and 26.3˚ for the H-plane, respectively. The breast phantom is irradiated by both proposed and conventional grid antenna arrays for 10 minutes. The proposed grid antenna array achieves 8˚C temperature increase within the breast phantom area compared to 2˚C temperature increase for conventional one. The proposed grid antenna array is highly efficient, high gain and light weight, and it has a very suitable radiation property for hyperthermia breast cancer therapy.

## Keywords

Breast Cancer, Hyperthermia, Grid Antenna Array, Pencil Beam

## 1. Introduction

Breast cancer is globally the most common type of cancer among women. Treating and developing low cost detection system are a clinical need for breast cancer disease. Hyperthermia is a type of cancer treatment in which body tissue is exposed to high temperatures using electromagnetic technology [1] [2] [3]. The goal of hyperthermia for cancer treatment, including breast cancer, is to elevate the temperature to above 42˚C at the tumor location for a sufficient period of time while maintaining a normal temperature in other areas [4].

Previous studies had shown that microwave hyperthermia is a promising noninvasive treatment for breast cancer [5]-[10]. The performance of ultra-wideband and narrowband microwave hyperthermia based on beam forming was investigated theoretically in [11]. Different shapes of antenna were used for temperature elevation purpose such as planer array, circular array, square octagonal planar slot line resonator, and hemispherical directive microstrip spiral array [12]-[18].

**Table 1** shows different temperature increase, input power, resonant frequencies and different exposure time of the aforementioned antennas. These parameters are indispensable for hyperthermia therapy. In [19], 2˚C was obtained at 4.5 GHz with minimum exposure time of 0.17 minutes and minimum input power of 0.71 watts among all. So, this system is the most promising one for human safety and effective temperature increase on human tissues. In this system, tapered slot circular antenna array was introduced for cancer treatment purpose.

All the aforementioned antennas had very complex feeding systems and very complex array shapes. The problem will arise from the number of cables, switching system, power dividers and even timing and controlling electronic circuits that will be needed for that type of antenna arrays.

In this paper, light weight grid antenna array with simple probe feed and very suitable radiation characteristics is proposed. Firstly, a conventional grid antenna array is investigated for hyperthermia applications. The unsuitability of the conventional grid antenna is ensured for that kind of application. As a solution, the horizontal elements of the conventional antenna array are modified for radiation characteristics enhancement purpose. The proposed grid antenna is designed, simulated, fabricated and its radiation characteristics are investigated for its suitability for hyperthermia applications. Finally, the proposed grid antenna array is simulated with incorporation of breast phantom at a distance of 60 mm from the proposed grid antenna array. The breast phantom is exposed to the antenna's electromagnetic wave for 10 minutes and with 0.5 watt at the antenna

**Table 1.** Comparison among different microwave hyperthermia antenna types.

| Ref | Temperature increase (˚C) | Exposure time (Minutes) | Input Power (Watt) | Resonant Frequency (GHz) |
|---|---|---|---|---|
| [12] | 3 | 8.65 | 1 | 1.6 |
| [15] | 6 | 30 | 45 | 4.2 |
| [16] | 12 | 3 | 50 | 0.434 |
| [18] | 5 - 6 | 70 | 19.2 | 0.434 |
| [19] | 2 | 0.17 | 0.71 | 4.5 |

input. The simulation shows that, breast phantom temperature has been raised to 8˚C above its normal temperature when the proposed grid antenna array is used. Also, temperature raise of 2˚C is obtained when conventional antenna array is used.

## 2. Conventional Antenna Array, Design and Simulation

Figure 1 shows the conventional grid antenna array with array element length $L$, array element width $S$, array length $b$ and array width $a$. For design purpose and based on [20], the following design equations are used for conventional grid antenna array design.

$$L = \lambda_g = \frac{\lambda_0}{\sqrt{\varepsilon_{eff}}} = \frac{c}{f_0\sqrt{\varepsilon_{eff}}} \tag{1}$$

$$S = \frac{\lambda_g}{2} \tag{2}$$

where $c$ is the velocity of light in free space, $\varepsilon_{eff}$ is the substrate's effective permittivity, $\lambda_0$ is the free space wave length and $f_0$ is the array resonant frequency.

The gain of the conventional grid array was calculated in [20] by:

$$g_1(n) = 216 - 0.52n + 0.1n^2 \tag{3}$$

$$g_2(n) = -143.2 - 1.13n + 0.058n^2 \tag{4}$$

$$g_3(n) = 30.3 + 0.7n \tag{5}$$

where

$$Gain[\text{dBi}] = \frac{g_1(n) + g_2(n)\varepsilon_r + g_3(n)\varepsilon_r^2 + 10\log(n)}{\varepsilon_r^3 h} \tag{6}$$

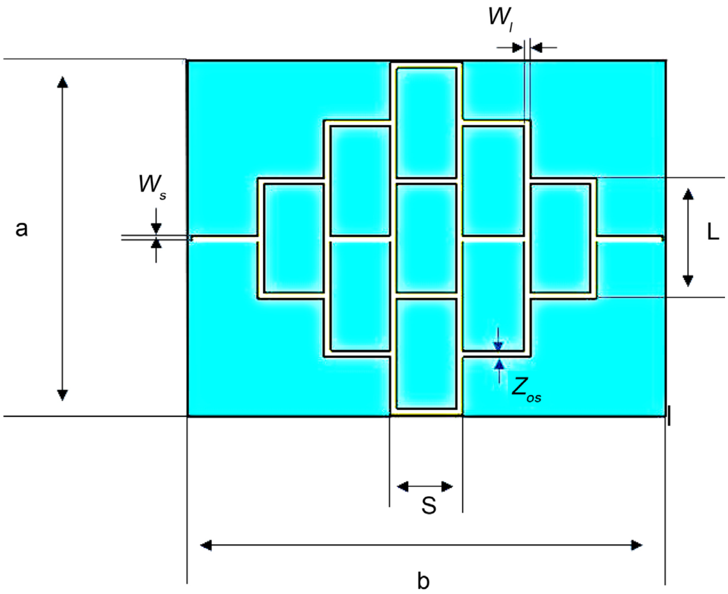


Figure 1. Conventional grid antenna array.

where $n$ is the number of radiating elements, $g_1(n)$, $g_2(n)$ and $g_3(n)$ are in dB and $h$ is the substrate thickness in mm. For verification purpose, a 4.86 GHz conventional grid array, is designed. This frequency is chosen for its suitability for the hyperthermia application as it was described in [15] [19] [21].

Using Equations (1) and (2) $L$ and $S$ are found to be 40.45 mm and 20.22 mm, respectively.

The grid widths, $w_l$ and $w_s$ are impedance, transmission, and radiation dependent parameters. The long sides are mainly considered as a transmission lines. They are responsible for the undesired cross-polarized radiation. Hence, narrower width $w_l$ will be preferable to reduce the undesired cross-polarized radiation. As width $w_l$ becomes narrower, impedance and transmission loss will increase significantly. Above 250 Ω, transmission loss increases rapidly so, the width, $w_l$ should be kept lower than 250 Ω. The short sides are considered as both transmission lines and radiating elements. They are responsible for desired copolarized radiation. The currents on them can be uniformly distributed, or tapered by varying the width $w_s$ [19].

For conventional grid antenna array design purpose, characteristic impedance of 57 Ω is chosen for both element long and short sides. When material with dielectric constant $\varepsilon_r$ of 2.2 and thickness of 0.787 mm is used, the short and long side widths are found to be 2 mm.

Conventional grid antenna gain is calculated and is found to be 7.37 dBi. Conventional grid antenna is simulated using Ansoft CST simulator version 14. **Figure 2** shows the obtained S-parameter of grid array where a resonant frequency of 4.83 GHz is obtained. RT/5880 material is used as antenna substrate with $\varepsilon_r = 2.2$ and thickness $h$ of 0.787 mm. Gain of 9 dBi and efficiency of 52% are

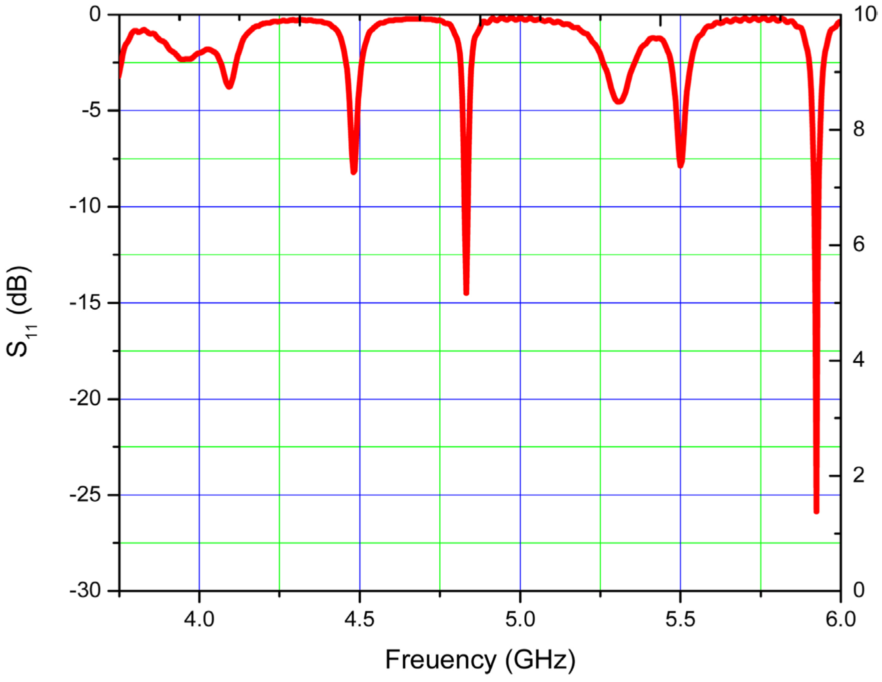


**Figure 2.** Simulated S-parameters of the conventional grid antenna array.

obtained at 4.83 GHz. **Figure 3** shows the 3D radiation pattern of the conventional antenna. It can be noticed that the main lobe direction at −16˚ and grating lobe direction at 16˚. The appearance of grating lobe make the radiated power concentrated at two directions, one for the main lobe and the other for the grating lobe one.

The existence of the grating lobe makes conventional grid antenna unsuitable for hyperthermia applications.

## 3. Proposed Grid Antenna Array Design, Simulation and Fabrication

The conventional grid antenna transmission and radiation properties are governed by short side width $w_s$. The proposed grid array short width is varied to obtain a suitable radiation characteristics for hyperthermia applications. Grid antenna array of 16-elements is presented in **Figure 4**, for breast cancer hyperthermia application. It is based on the modification of horizontal grid elements' widths and investigating the effect on the radiation characteristics. Now, the horizontal element is treated as single microstrip antenna rather than simple microstrip line. As the microstrip antenna width increases, their directivity and gain increases too. The width of the microstrip antenna should be one half of the guided wavelength for antenna radiation efficiency enhancement [21]. The proposed antenna array should have high gain and efficiency by varying the grid antenna array short side width $w_s$. The proposed antenna array has simple probe feed and simple construction method. The difference between the half-power beam widths of the E- and H-planes is used to assess the pencil beam quality. The prototype is designed and fabricated on RT/Duroid 5880 substrate. This substrate is chosen for its low loss tangent and its low dielectric constant which are two important parameters for any microstrip antenna construction. The proposed

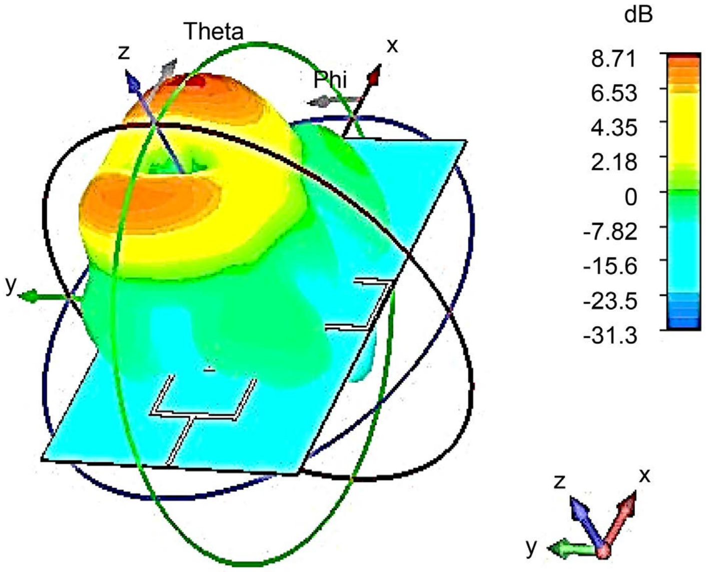


**Figure 3.** Simulated radiation pattern of the conventional grid antenna array at 4.83 GHz.

grid antenna array size is 150 × 175 × 1.5 mm$^3$. The substrate dielectric constant and loss tangent are $\varepsilon_r = 2.2$ and $\tan\delta = 0.0009$, respectively. A metal reflector with 20 cm × 20 cm and at 9.5 mm from the antenna is used for gain enhancement purpose. The proposed grid array is analyzed using (CST) simulator. Figure 5 shows the simulated $S_{11}$ results for the microstrip grid array antenna.

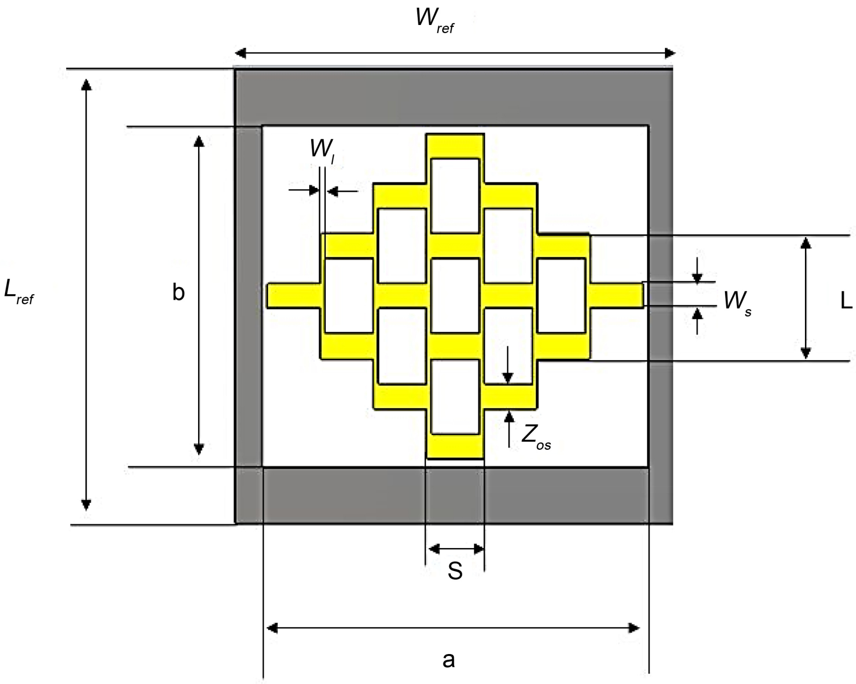


Figure 4. Proposed grid antenna array.

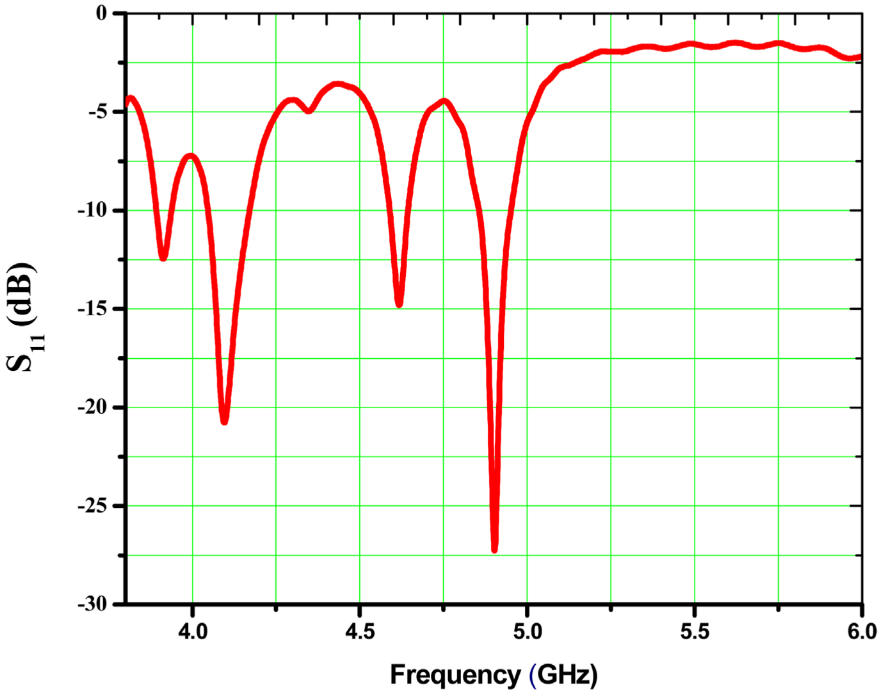
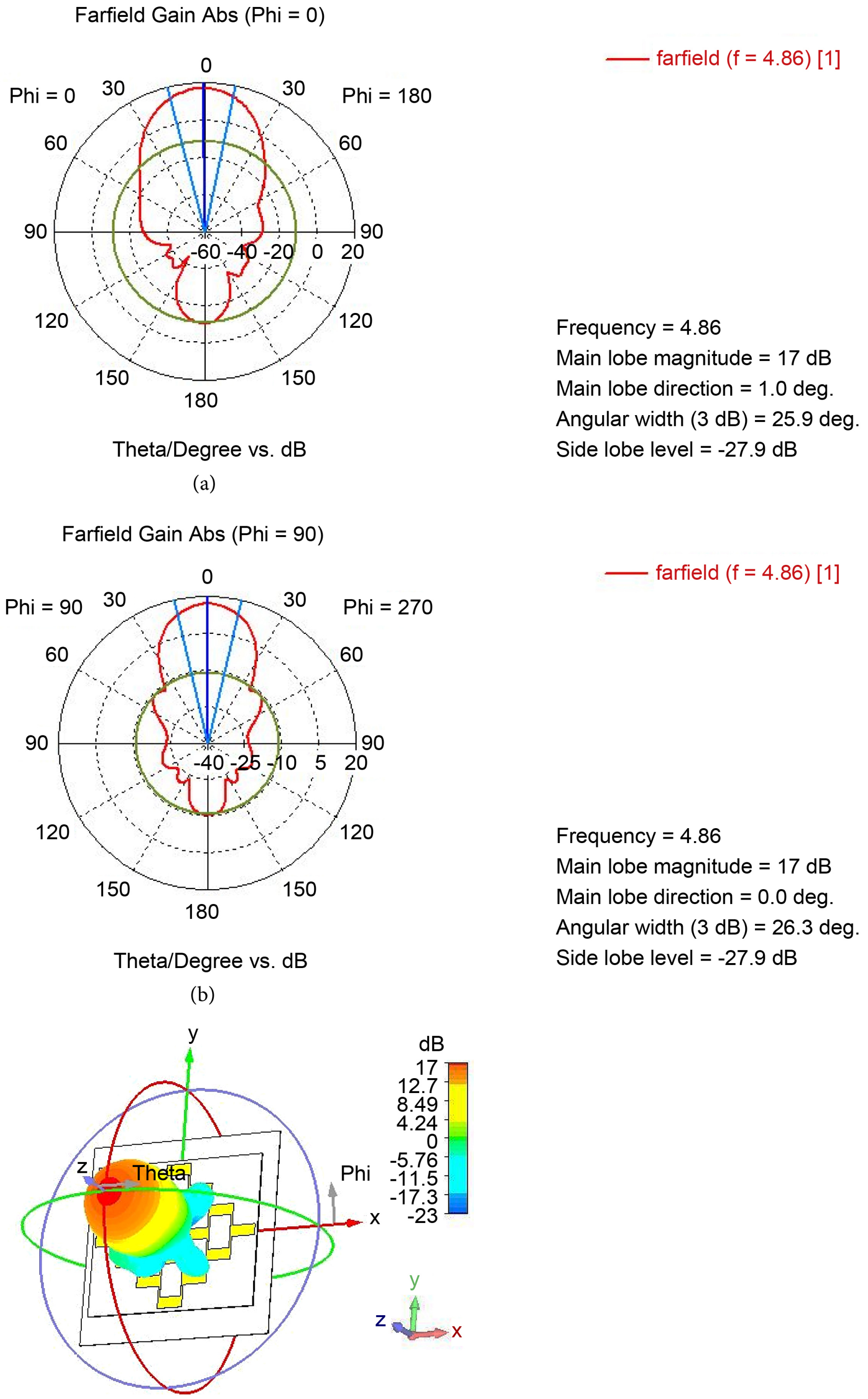


Figure 5. Simulated $S_{11}$ of the proposed grid antenna array.

The proposed antenna bandwidth is extended from 4.8 GHz to 4.9 GHz at resonant frequency of 4.86 GHz, **Figure 5**. The length of the horizontal element is 26 mm and the element width is 11 mm. The simulated half-power beam width is 25.9˚ in the E-plane and 26.3˚ in the H-plane at 4.86 GHz, **Figure 6**. **Figure 6** indicates that a pencil beam radiation is obtained. The proposed



(a)

(b)

(c)

**Figure 6.** Simulated radiation patterns of the proposed grid antenna array at 4.86 GHz, (a) E-plane, (b) H-plane and (c) 3 D radiation pattern.

antenna array has a gain of 17 dBi, fractional bandwidth of 2.1% and efficiency of 93% at 4.86 GHz. Figure 7 shows a photo of the proposed fabricated grid antenna array.

Figure 8 shows the measured and the simulated results of the proposed grid antenna array. Fractional bandwidth of antenna is the antenna's bandwidth divided by its resonant frequency. The proposed antenna achieves 2.1% measured fractional bandwidth. It is evident from the figure that the measured-10 dB impedance bandwidth is 0.1 GHz and it extends from 4.85 to 4.95 GHz for the microstrip grid array antenna at resonant of 4.9 GHz. The discrepancies between the simulated and measured $S_{11}$ results are mainly caused by soldering and warpage. It is found during the measurements that $S_{11}$ result is very sensitive to probe position and soldering process. This is because, the probe feed position has specific values of electric field, surface current and of course, specific impedance

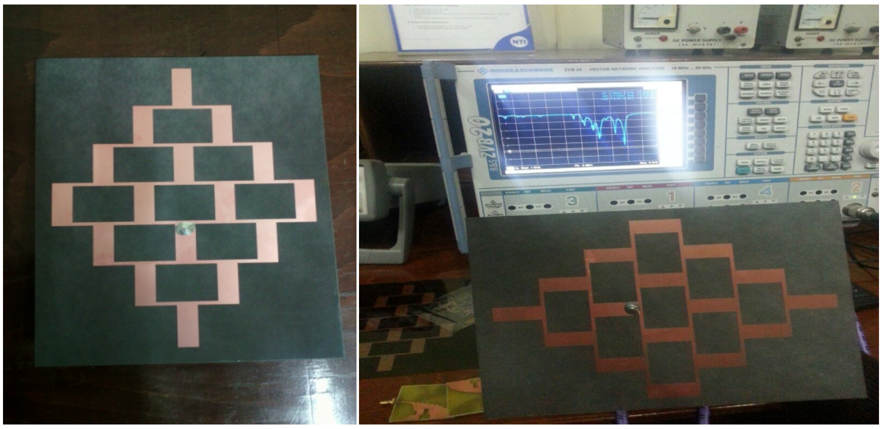


Figure 7. Fabricated grid antenna array photo.

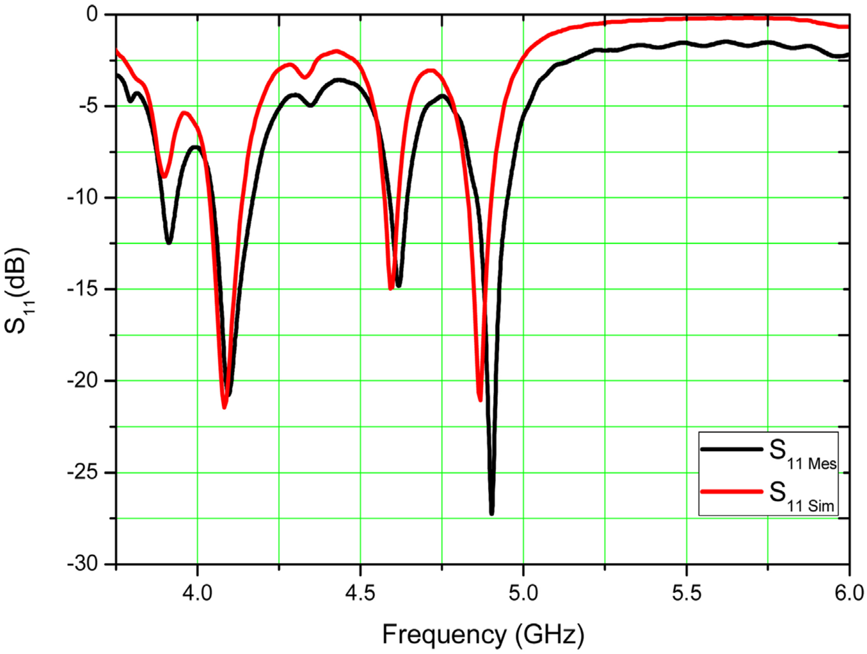


Figure 8. Simulated and measured $S_{11}$ of the proposed grid antenna array.

value. So, any position offset will cause impedance variance and that will affect directly the matching between antenna and the coaxial 50 Ω connector.

## 4. Proposed Simulated Hyperthermia System

Breast phantom for microwave hyperthermia has been reported in [22]. It was built using mixtures of low-cost materials such as water, oil, salt, gelatin and formaldehyde. These materials were utilized to meet the tissues' dielectric permittivity, conductivity, and thermal properties across the frequency band 3 - 6 GHz. Table 2 shows the materials properties which are used in building breast phantom in CST simulator. Both conventional and proposed grid antenna arrays are used for obtaining the temperature distribution inside the breast phantom.

Figure 9 shows the simulated system where conventional grid antenna array is placed at 60 mm from the breast phantom and at a frequency of 4.83 GHz. Figure 9 shows the thermal distribution after 10 minutes and with 0.5 watt at the antenna input. The temperature distribution is not uniform inside the phantom due to the heterogeneous structure of the breast. The simulated temperature increases from 38˚C to 40˚C within the phantom area. This temperature increase is insufficient for breast cancer treatment process.

Figure 10 shows the proposed simulated system where the proposed grid antenna array is placed at 60 mm from the breast phantom and at a frequency of 4.86 GHz. Figure 10 shows the simulated thermal distribution after 10 minutes

Table 2. Thermal properties of breast tissues.

| Tissue types | Density (kg/m$^3$) | Specific heat capacity (J/g˚C) | Thermal conductivity (W/m˚C) |
|---|---|---|---|
| Fat | 1069 | 2.28 | 0.3 |
| Skin | 1085 | 3.77 | 0.4 |
| Tumor | 1050 | 3.6 | 0.5 |

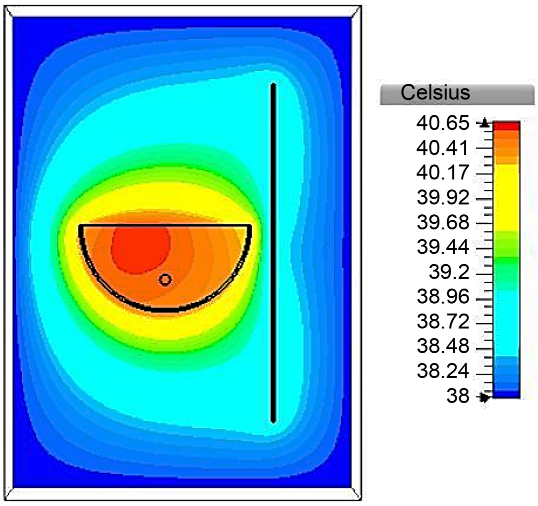


Figure 9. Heat distribution in breast phantom using conventional grid antenna array.

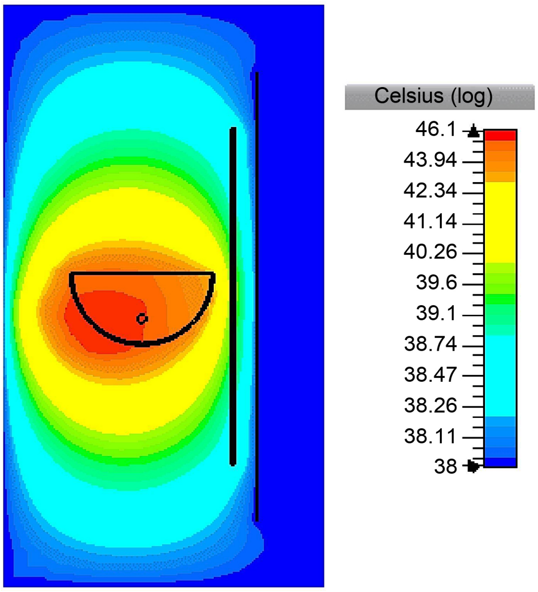


**Figure 10.** Heat distribution in breast phantom using proposed grid antenna array.

and with 0.5 watt at the proposed grid antenna array input. A realistic temperature of 38˚C is chosen for the body and the background temperature. The simulated temperature increases from 38˚C to 46˚C within the phantom area. This temperature increase is very sufficient for breast cancer treatment process.

## 5. Conclusion

In this paper, temperature raise of 8˚C in breast phantom area was obtained, resonant frequency of 4.86 GHz for breast hyperthermia therapy was used, CST Microwave Studio simulator for combining the electromagnetic and thermal simulation results was used, and breast phantom temperature distribution while using both proposed and conventional grid antenna arrays was shown. The breast phantom was irradiated for 10 minutes and with 0.5 watt at antenna input. The conventional grid antenna array achieved temperature raise of 2˚C in breast phantom area. This temperature increase is insufficient for hyperthermia therapy. The conventional grid antenna array short side was modified for radiation properties enhancement. The proposed grid antenna array long side width was kept wide for losses reduction. The proposed antenna gain, efficiency, 3 dB beamwidth, and its structure were very suitable for hyperthermia applications. It is worthy to mention that the proposed hyperthermia grid antenna array system raises all breast tissues to 46˚C without any discrimination between tumor tissues and breast tissues. So, very careful medical procedure needs to be considered when using this type of cancer treatment.

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