2013 IEEE MTT-S International Microwave Workshop Series on
RF and Wireless Technologies for Biomedical and Healthcare Applications (IMWS-BIO)

Microwave Near-Field Effects and Characterizations for Non-invasive Breast Cancer Treatment

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***Abstract* — In this paper, a circular conformal radiation system is considered for the quadrant breast cancer therapy. A toroidal conformal antenna is proposed for nipple area breast cancer therapy. The *s*pecific *a*bsorption *r*ate (SAR) values in the breast model are analyzed based on simulated results using finite element method (FEM) in HFSS software. Different sizes of toroidal antennas are assumed in simulations to find the best focusing effects in the tumor region. By comparing various simulation results, it is concluded that focusing effects in tumor region vary with sizes of antennas. At the same time, a preliminary biomedical system is proposed for adaptive therapy of breast cancer tumors with arbitrary positions. The high treatment efficiency is achieved by varying feeding signal phases on the two antenna patches for different beam scanning.**

***Index Terms* — thermotherapy, noninvasive, conformal antenna.**

I. Introduction

According to the statistics by the World Health Organization, the morbidity rate of breast cancer rises continuously in developing countries, especially in China [1]. Almost 0.5 million women are diagnosed with breast cancers, and 0.2 million women died. Microwave thermotherapy is a relatively prevalent form of cancer therapy. It artificially increases tumor temperature to a peak value that is usually between 42 and 45℃ while attempting to keep the remaining breast tissue at a safe and comfortable level. In microscopic level, the SAR value obtained in different kinds of tissues is related to their respective average complex permittivity values ($\varepsilon^*=\varepsilon'-j\varepsilon''$), *i.e.*, their relative permittivity (ε_r) and conductivity (σ) values [2].

Traditional method for breast cancer treatment mainly relies on surgery combine with drug delivery and Chemotherapy. However, hair loss, nausea, even leukemia and other side effects are caused. Patients without breast-conserving therapy have to suffer physical and psychic traumas. Therefore, novel, efficient and less-damaging medical instruments are desirable to improve patients' therapy effectiveness and comfort.

Bra, a well-accepted daily experience for women, is chosen as the basic form in the present designs and it serves as a supplementary component part of microwave noninvasive breast cancer instruments. This proposed device is assumed to be worn daily for a couple of hours in regular life meanwhile it will heat the tumor gradually for treatment purpose. In this case, a chargeable, compact and portable battery should also be considered as an attachment of the system for the purpose. It is easy to be removed, cleaned and recharged. This paper will show some basic research results about conformal antenna designs for non-invasive breast cancer thermotherapy.

II. Problem Definition and Analysis

Clinical data show that there are five tumor formation areas as show in Fig. 1(a). These are the upper outer quadrant, the lower outer quadrant, the upper inner quadrant, the lower inner quadrant breast, and the nipple. The morbidities in these areas occupy 60%, 12%, 12%, 6%, and 12%, respectively. Therefore, two schemes are proposed here for various cases.

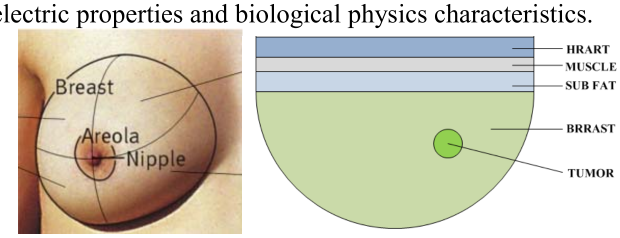
A. One Set of Adjustable Equipment

In this design, we consider only one system with tunability. Because of the fluctuating position of the breast tumor cells, we are able to adjust the phase and amplitude of signals through other factors to achieve a set of equipment for scanning and radiating different therapy positions.

B. Two Sets of Fixed Equipment

According to possible positions of the breast tumor cells, it can be summarized into two parts: the nipple and quadrants. Due to different pathological conditions, two systems are proposed to simplify antenna design complexity.

In this paper, we will present some basic ideas implemented in the above-mentioned two antenna designs, followed by some numerical simulations and calculations of the SAR values inside the beast model comprising of the cancer tumor cells. Of course, the human breast biological system and its characteristics are very complicated, and there are a lot of unknowns about the breast cancer tumor cells and their electric properties and biological physics characteristics.



(a) (b)

Fig. 1: (a) Upper/lower inner/outer quadrants and nipple area considered in antenna designs, and (b) its electric model.

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III. Numerical Modeling and Antenna Designs

A. Numerical Modeling

Based on a realistic phantom repository available from in the Computational Electromagnetics Group at the University of Winsconsin [3], the breast electrical model used in our simulation is shown in Fig. 1(b). Early breast cancer tumor sizes usually range from 0.1 cm to 3 cm, with an average size of 1 cm. So, we take the average size of 1 cm as an example in the designs. The dielectric material parameters of breast tissues were provided by the IFAC [4] and are used here in simulations and designs. Their dielectric properties are shown in Table 1 below.

TABLE 1
Dielectric Properties of Breast Tissues at 2.45 GHz

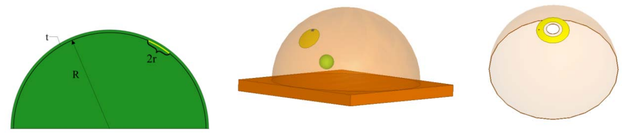
Tissue	Conductivity [S/m]	Relative	Loss tangent	Wavelength [m]	Penetration depth [m]
Breast fat	0.13704	5.1467	0.19535	0.053684	0.0883
Heart	2.2561	54.814	0.30199	0.016346	0.017614
Muscle	1.7388	52.729	0.24194	0.016731	0.02233
Fat	0.10452	5.2801	0.14524	0.053113	0.11702
Tumor	1.6667	62.77			

B. Antenna Designs

The circular microstrip conformal antenna and the toroidal ring antenna are proposed in this paper, and they are designed to respectively heal the quadrants and the nipple as planned earlier. Like a spheroid, the breast is considered to be approximately symmetrical. Therefore, different quadrants can be seen as one side of the symmetrical system, so as to simplify the designs. The schematic diagrams and the side view and 3-dimensional view of the circular microstrip conformal antenna patch are shown in Figs. 2(a) and 2(b) while the toroidal ring microstrip antenna is shown in Fig. 2(c) in its top view.

The proposed circular microstrip patch antenna shown in Figs. 2(a) and 2(b) is considered and utilized for the quadrant thermotherapy. The thickness of substrate is 1.6 mm, and the relative permittivity is $\varepsilon_r = 4.4$. The patch is positioned at a proper angle to the breast model centre axis.

The toroidal ring conformal antenna is also proposed but for the nipple thermotherapy, as shown in Fig. 2(c) in its top view. The thickness of substrate is also 1.6 mm, but the relative permittivity is chosen as $\varepsilon_r = 2.2$. The toroidal ring patch with the substrate is positioned on the top middle for maximizing the nipple area's thermotherapy. The inner and outer radii of the ring can be changed in accordance with the different patients' physical sizes and the practical locations and dimensions of cancer tumors so as to obtain differently focused power distributions.



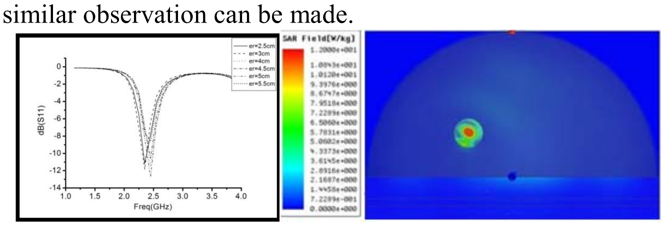
(a) (b) (c)

Fig. 2. Circular antenna mounted on the surface of semi-spheroidal breast model: (a) Side view and (b) 3D view for the breast cancer tumor located in different quadrants; and a toroidal ring antenna amounted around the breast nipple for microwave thermotherapy: (c) top view.

IV. SAR Calculations and Discussions

A. Quadrants Thermotherapy

As mentioned earlier, the circular microstrip conformal antenna is proposed to ablate the tumor in quadrants. The antenna is designed to resonate at the frequency of 2.45 GHz. It has the focused power distribution in the tumor area as seen in Fig. 3(a), whose general power distributions and absorptions will be addressed later in detail. The power is attenuated very fast through the highly lossy tissue materials such as muscles and sub fats, as shown in Fig. 3(b). Therefore, the antenna has almost no side-effect on human inner chests including hearts. In terms of the specific absorption rate (SAR) values, it is apparently seen that the microwave thermotherapy is quite safe to the patients as shown in Fig. 3(b). We have obtained a lot of other results on this side effect, and the similar observation can be made.



(a) (b)

Fig. 3. (a) S11 parameters of the circular microstrip antenna with different substrate permittivity values; and (b) Power distribution in inner chest close to heart.

When the tumor location is changed, for instance, the tumor depth increased, the SAR value and distribution are both varied as shown in Fig. 4. To demonstrate such effects, we have considered various different locations of breast cancer tumor, while the antenna position is maintained. As shown in Figs. 4(a) and 4(b), the power distribution focused on cancer tumor due to a simple circular conformal antenna varies when its radial distance from the centre of the breast model is changing from 2.0 cm to 5.5 cm at an interval of 0.5 cm.

It is seen that (i) the microwave thermotherapy is very effective and safe, without causing unnecessary influence on other cells and organs as shown in Fig. 4(a); (ii) the therapy efficiency is high when the cancer tumor is close to the breast surface as shown in Fig. 4(b); but (iii) it is less efficient when the cancer tumor position is further inside the middle of beast model as shown in Fig. 4(c).

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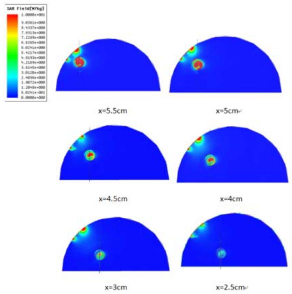
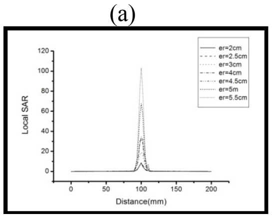


(a)



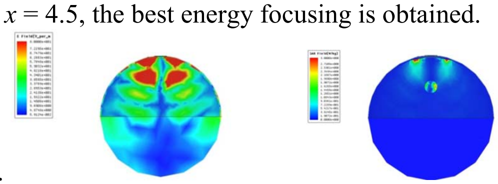
(b)

Fig. 4. (a) SAR distributions of quadrant tumors in different locations, and (b) the local SAR distribution peak values.

B. Nipple Thermotherapy

The toroidal ring antenna shown in Fig. 2(c) is positioned at the top middle of the resonance at a frequency of 2.45 GHz. The nipple connects with mammary gland with a high relative permittivity. It is thus easy to develop high temperature under microwave radiation. Therefore, we choose toroidal thin ring antenna to avoid overheating. Based on physical theory, electrical characteristics of cancer tumor in the nipple area are much different from those of other areas. The SAR distribution is directly related to the electric field distribution, so we build a section in the centre of the model to observe effects of SAR parameters, as shown in Fig. 5. It is observed in Fig. 5(b) that the power is primarily distributed around the ring and the power in the middle is very weak.

To obtain a focused power distribution or SAR on cancer tumor, we adjust the inner and outer ring radii to maximize the therapy effects, as shown in Fig. 6. We consider different sizes of ring antennas, where x = 3, 4.5, and 5. It is realized that when x = 4.5, the best energy focusing is obtained.



(a) (b)

Fig. 5 . Electric field distribution and its defocusing SAR

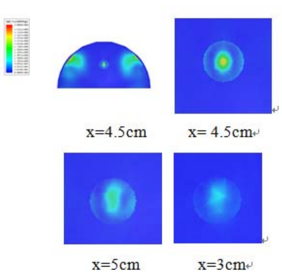


Fig. 6. Electric field distribution with focused SAR distribution

V. PHASE INFLUENCE

Both amplitude and phase of the input signal are important in the antenna designs. The phase variable can be considered as another degree of freedom. The electric model is thus built with two conformal circular patches. When the cancer tumor is located at off-centre coordinates of (0, 4.5, 4.5), simulation results in one cycle are shown in Fig. 7(a), where the minimum value of SAR acquires with an antiphase feeding. When the cancer tumor is located in the central position at coordinates of (0, 0, 4.5), simulation results in one cycle are shown in Fig. 7(b), where the maximum value of SAR is obtained with antiphase feeding. This helps us to maximize the microwave thermotherapy in an efficient way and some system set-up flexibility.

VI. CONCLUSION

A circular microstrip conformal antenna for the quadrant breast cancer therapy and a toroidal thin ring conformal antenna for the nipple area breast cancer therapy are proposed and their related results are presented. The circular conformal antenna patch has the best focusing power distribution when the tumor is right below it. The torodial ring antenna should be utilized in line with tumor position below the nipple area. In summary, an efficient antenna system can be designed in accordance with the patients' antenna positions. Finally, the phase shifts are also considered and their influence to the therapy is also discussed, as an additional freedom to make equipment system adjustable with some flexibility.

ACKNOWLEDGEMENT

The authors are grateful to the financial support by Project No. 61171046 from National Science Foundation of China.

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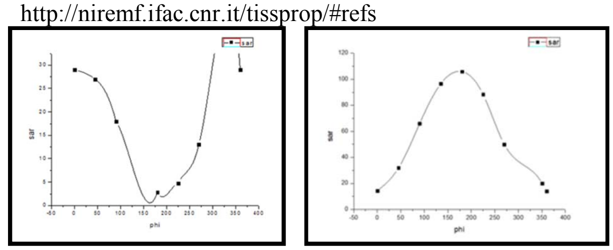

(a) Noncentral position (b) Central position

Fig. 7 One cycle SAR value calculations using phase shifts.