Microstrip Near-Field Focusing for Microwave Non-invasive Breast Cancer Thermotherapy

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Abstract

In this paper, a novel focusing method in non-invasive microwave thermotherapy for breast cancer is proposed. Since the antennas used in the non-invasive microwave thermotherapy devices are no longer working as a far field transmitter, only its near field characteristics are critical to the performance of the system, design methods and principles have to be refreshed towards a better thermotherapy device. The method proposed in this paper focuses on the application of microstrip structure in these systems, is based on the nature of near field characteristic of microstrip antenna, thus to enhance the energy density of the target area. This novel device will achieve near field focusing effect by using single antenna, instead of antenna array, lenses or other methods that are usually utilized in communication systems. The focusing effect is verified and demonstrated by well-designed numerical experiments, and the results show that this method is very promising in the treatment of breast cancer.

1. Introduction

Microwave thermotherapy is a promising method towards the fighting against breast cancer, along with standard treatments include surgery, radiation therapy, chemotherapy, and hormonal therapy[1]. An invasive thermotherapy can achieve high-efficiency much more easily than a non-invasive one, because of that the invasive device is put in the middle of the target area to literately heating the cancer tumor from inside. However, non-invasive therapy will be more attractive considering the potential scars leave on patients' skin in invasive therapies, along with the cost and other drawbacks. Also, it can be equally efficient if the non-invasive therapy evolved into a focused one. Focusing microwave systems usually utilize phased array techniques, which will end up with a very complex system[2]. It is also valid with other recent progresses such as time-reversal focusing system[3]. In our group, several schemes of microwave thermotherapy system have been studied[4-7] including both invasive and non-invasive thermotherapies. In this paper, a focusing method is proposed for conformal microstrip microwave breast cancer thermotherapy.

2. Non-invasive Microwave Thermotherapy System

In this chapter two different kinds of non-invasive microwave thermotherapy that has been developed in our research group will be introduced. Both of them are using microstrip antenna as the radiation interface for the thermotherapy system. The first scheme is a medical microwave device that using one conformal patch antenna is introduced. A circular conformal patch antenna is located symmetrical on the center axis, assuming that the breast is in an ellipsoid shape for the convenience of analyzing. The system is shown in Fig 2.1[5], a relatively big conformal patch is designed, and the tumor is located in the deep area of the breast. Though it has been studied in our previous work, but the near field characteristics along with more potential of the system is still an interesting and significant topic to dig, this is alsot the purpose of this paper. More analyses of this system will be introduced in the following chapters in this paper.

The second scheme is a conformal microstrip antenna that is used for the purpose that the electromagnetic energy could flow into the target area by adjusting the position of the patch, as shown in Fig 2.2[6]. Basically the adjusting principle is to assure the tumor is located on the axis of the patch. This system is developed in our group to be able to be fitted into a wearable device that suits daily wearing usage, to cure or remit or avoid breast cancer. The biggest different of two systems is that the patch in this scheme is smaller; this is because that the room on the surface of woman underwear is small.

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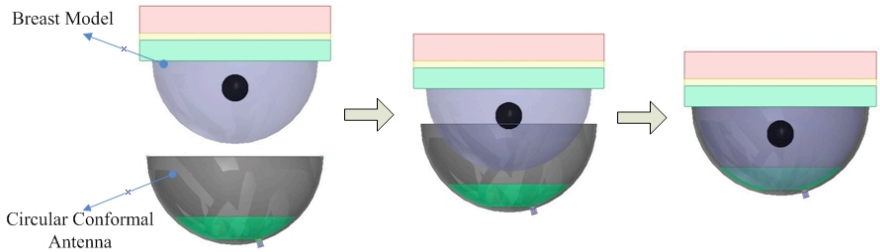

Fig 2.1 Symmetrical microwave thermotherapy System(Scheme I)

In both of the systems that have been studied in our group, high efficiency can be achieved, but the ultimate focusing effect is not assured under the current schemes. Which means it is not fully controllable while a focusing point is being designed. Thus a more accurate physic model should be build toward focusing issues, which is a big challenge on the path of a practical solution.

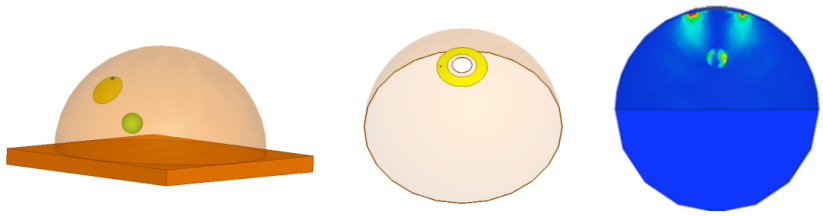

Fig 2.2 Wearable microwave thermotherapy System(Scheme II)

3. Focusing Enhancement in Microstrip Thermotherapy System

In this chapter, near field characteristics of traditional rectangular microstrip antenna will be analyzed and then be extended for a conformal circular microstrip system, thus to further study its application in thermotherapy systems.

Microstrip antenna is well developed for communication and radar system for decades. The principle of microstrip antenna is well described in documents. Among those explanations and describes, a vivid image is that to consider the microstrip antenna is equivalent to two slots that emits electromagnetic wave due to the discontinuity of electric flux line on two narrow edge of the patch. Thus a microstrip antenna can be understood as two slots located half wavelength away, therefore their radiation patterns will synthetize in the far field, result in a directive radiation pattern. This will definitely help to understand the method that will be proposed in this paper. Despite the far field radiation pattern synthesis, in the near field area, it also can be concluded that the electromagnetic energy will be emitted through these two “slots”, as shown in Fig 3.1(a). The direction of this energy flow can be seen as perpendicular to the ground for understanding the principle in a simpler physical picture. Of course, in real case the near field of antenna is much more complex, but it won’t vary too much from the basic physics for most of the cases.

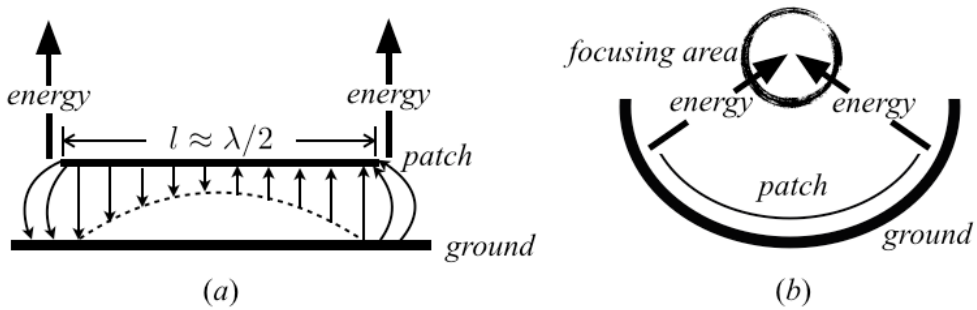

Fig 3.1 (a) The physical picture of energy flow of a traditional rectangular patch antenna. (b) The physical picture of energy flow of a conformal circular patch antenna used in thermotherapy device.

In a system in scheme I, a microstrip structure is used as radiation interface of the system. The reason it will not be called an antenna is that it is not working as an antenna, but still the basic principle is the same. Consider folding a rectangular patch antenna into curved shape, in its cross section level, and then rotate it for180 degree thus the image in Fig 3.1(a) will evolve into the one in Fig 3.1 (b). Still, of course, the picture is a rough one, a demonstration; the real case energy flow will be shown in the following section of this paper. In this picture, it is clear that the energy will flow into a mutual area that is the area where the perpendicular energy flow lines are intersected. Though the energy will

transmit through this area and separate in the far field, it is not in the best interests for the system design, due to that the far field is not in the consideration of a system like this one. The device will perform badly as an antenna, due to its untrimmed radiation pattern. However the energy will be cut or absorbed before it reaches far field regime in thermotherapy systems. In this case, muscles and other tissues will absorb the energy, no matter what, the far field radiation is needed to be suppressed for safety consideration.

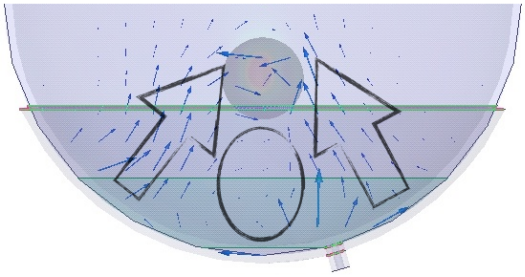

Fig 3.2 Distribution of Poynting vector on the cross section of the scheme I system.

To better demonstrate the physic of this concept, a simulation is conducted to show the energy flow in a system like mentioned before. A distribution of Poynting vector on the cross section of the system in 2.1 is plotted in Fig 3.1.2. It is very clear from Fig 3.2 the energy is flowing along the line that perpendicular to tangent plane of ground plane. In this case, two major energy fluxes flow can be observed and signed as two arrows. This result verified the previous physic analyses. On the contrary, the area that near the patch but in between two energy flow areas, which is signed as an oval, shows little energy density. In the oval area, the energy is suppressed, particularly in breast cancer treatment, nipple are located exactly in this area, which indicated that this scheme could protect nipple area by its physical nature.

Next, the concept will be verified by numerical simulation. The simulation configuration is described in Fig 3.3. After all, an assumption is made that the system has a focusing point/area that located in a guessed area along the center axis. The cancer tumor is also located at the axis, between the assumed focusing point and the patch, the relative distance between the focusing point and the tumor is *d*. In this configuration, the distance between the tumor and the patch is shorten while *d* is increasing, this will avoid the effect that the field density will attenuate in the route. In the simulation, SAR_max is the parameter of interest, which indicates the maximum SAR inside the tumor. The detailed simulation setup parameter can be obtained from our previous paper[5]. It is reasonable to choose moving the tumor around instead of fixing the position of tumor then adjusting the design of the system to verify the concept, that is, it is much more easier way to demonstrate the idea. It is easy to alter the parameter of the microstrip device to get a different focusing point in this axis-symmetrical system, however the feeding point will also be redesigned, which could bring additional variation to the results. In this paper, the way that the verification is conducted is believed to be a more convincing one.

The simulation is performed in a FEM based commercial software, Ansys HFSS®. The simulated results are shown in the Fig 3.4, when d=0mm, SAR_max=302W/kg, d=5mm, SAR_max=272W/kg, d=10mm, SAR_max=280W/kg, d=15mm, SAR_max=245W/kg. This result shows that the SAR will rising while *d* is decreasing, which will indicate that a better thermotherapy efficiency is achieved, while the focusing point is designed as where the target tumor be. It is understandable that SAR_max at d=10mm is smaller than it at d=15mm, because of that the near field of the system could be very complicated and such phenomenon is possible to occur. Also it is OK if SAR_max are not strictly decreasing while d is increasing, because the target result is that SAR_max reaches is maximum value at d=0mm, which is exactly what the results show.

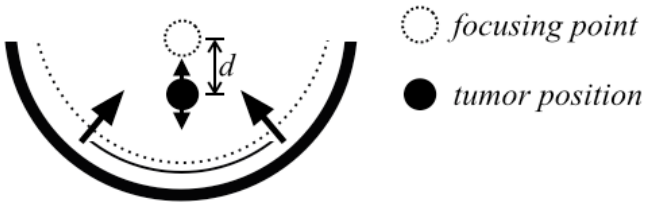

Fig 3.3 Simulation Configuration

Furthermore, considering that in most of the cases that the cancer is not located on the axis exactly, in these cases, the concept can also help to design a focusing system that its focusing point is on the right position. To achieve it, the patch should be designed off-axis, thus the system is no longer an axis-symmetrical system, therefore the focusing area will also moving to a bias position where the designer want it to be. In this case, the difficulty is left to the feeding network design, it will be more difficult to find the right feeding point on the patch due to the non-symmetrical

geometry. This part of working is on-going in our group, and will be published soon. Also the concept could contribute to the development of wearable system aforementioned.

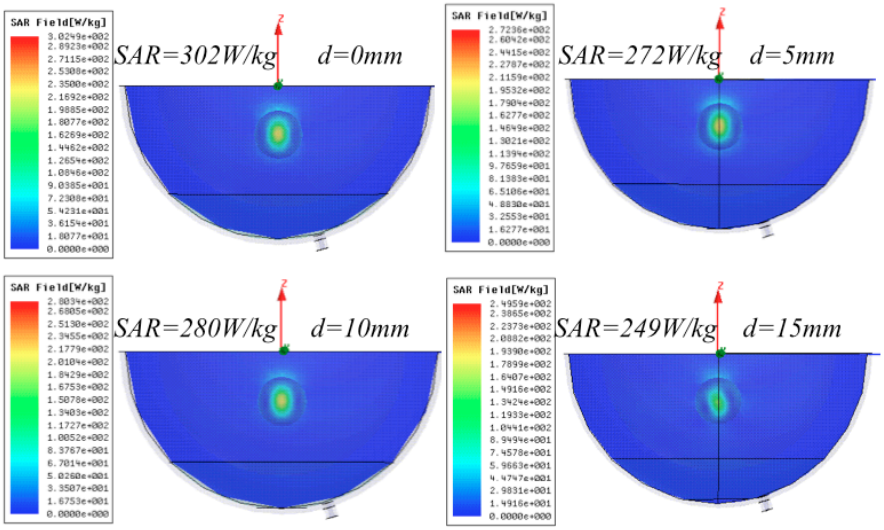

Fig 3.4 SAR distributions on cross-section for different d parameter.

4. Conclusion

In this paper, a novel focusing method in non-invasive microwave thermotherapy for breast cancer is proposed., after fully understood the near field characteristics of half-wavelength microstrip structures. A microstrip near-field focusing system is studied to verified the concept, furthermore to demonstrate the characteristic of the method. The results show that the system can heat the tumor while protecting the nipple area due to its near field nature. Moreover, the system can be easily extended to off-axis focusing application which will be more practical for breast cancer treatment. So far, this promising concept shows big potential in the future development of microwave thermotherapy for breast cancer. In the future, several numerical and experimental work along with the design of a prototype system will be conducted.

5. Acknowledgments

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