# Antennas for Hyperthermia Therapy

Sooman Park, Injong Seo, Geoncheon Lee, Yeongseog Lim
Dept. of Electronics Eng.
Chonnam Nat. Univ.
500-757, Yongbongdong, Bukgu, Gwangju
Korea

*Abstract:*-This study involves the design of coaxial-feed applicator to deliver microwave energy in appropriate shape to the target tissue without damaging normal tissue. To increase the efficiency of an antenna during microwave hyperthermia therapy, first, the length from the antenna end to a slot is varied to get the optimal matching of the characteristic impedance at the frequency of 2.45GHz. Hyperthermia is the method that raises center temperature of human tissue artificially and treats tumor. Using the electric and thermal constants of biological tissue, we compose a phantom to calculate temperature increment as well as the resonance characteristics and the SAR(Specific Absorption Rate) distributions. The proposed antennas inserted in an applicator plays an effective role in increasing the therapy size in the view of heating performance. The SAR is used in combination with the finite difference heat transfer equation to determine the temperature distribution. Also, in order to shorten treatment time and increase therapy size, we suggest an array antenna structure.

*key-words:*-SAR, Temperature, Hyperthermia, Antenna, Array, Applicator.

## 1 Introduction

The widely known application of microwave energy in medicine is the cancer treatment by means of localized hyperthermia.

This is a kind of cancerous tissue therapy to heat malignant tumors up to specific temperature without overheating the surrounding normal tissue. This technique involves the use of elevated temperature to hasten the destruction of cancerous tissue. At the elevated temperature, cells lose their ability to divide.

Once the materials to be used for the exact construction of antenna and insulation catheter are decided, impedance modeling process results in current distribution of the applicator, which are used in a field prediction process to determine the SAR distribution in the tissue of interest.

First, we analyze the slot antenna and modify the dimensions of antenna slot and length, which are related with the heating transfer characteristics. Using finite difference method, temperature distribution in the tissue-equivalent phantom model as a function of time and input power. The operating frequency is 2.45GHz, which is one of the ISM(industrial, scientific, and medical) frequencies.
Also, in order to shorten treatment time and increase therapy size, we suggest an array structure which have 2, 3 and 4 antennas.

The overall organization of this paper is as follows. Section 2 describes the definition of the SAR, and bio-heat transfer equation. In Section 3, by analysis of the applicator, the results of the SAR and the temperature increment distribution are described. In Section 4, the newly designed array applicator and its heating characteristics are described. Finally, some concluding remarks are made in Section 5.

## 2 Theory

Three parameters of critical importance in research of hyperthermia are temperature, time and focusing of heat. It is dependent on the type of applicator used. Desirable temperature and time relationships depend on physical and physiological characteristics of the cancerous tissue. It is important that heating be rapid and that the temperature distribution over the region of the cancerous tissue be as uniform as possible.

The SAR is defined as the power absorbed into the unit mass of tissue. After the excitation of electric power, the maximum electric fields are continually stored at all the location inside of human body inside. The more practical SAR equation is defined as

$$SAR = \frac{\sigma}{2\rho} \; |E_i|^2 \tag{1}$$

where $E_i$ is the peak value of electric field component. The constants σ and ρ denote the conductivity and mass density of the tissue. It is convenient to represent the SAR data as an analytical expression. Using a finite difference approximation, the SAR data is used to predict temperature increment during microwave power radiation.

A general form of the bioheat equation for the approximate modeling of the heating process in tissue is the Pennes' bio-heat transfer equation.

The temperature of tissue can be approximated as

$$\rho \cdot C_p \frac{\partial T}{\partial t} = K\nabla^2 T + \rho \cdot SAR - b \cdot (T - T_b) + W_m \tag{2}$$

where $\rho$ is the density of tissue, $C_p$ is the specific heat, T is the temperature of tissue, b is a blood flow coefficient, $T_b$ is the temperature of blood, $\nabla^2$ is the Laplacian of the temperature T, K is the thermal conductivity, the SAR is the input EM heating source into bioheat equation, and $W_m$ is the power generated by metabolism.

Temperature rise by EM wave can be obtained by difference of T(t) and T(0).

## 3 Design of the Applicator

To decide the peak voltage of a sine wave, we calculate the electric field density by adding the vertical component of Poynting vector of each of 6 sides at a distant point about 5 cells in absorption boundary surface. The simulation is interrupted when the total energy in the studied domain is reduced by 40dB, with reference to its maximum value. The characteristic impedance of the antenna is evaluated as the ratio between the Fourier transforms of the voltage and the current at the feeds.

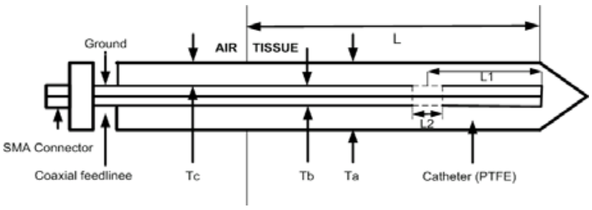


Fig.1 Basic schematic of the general applicator

The generalized representation of the structural detail associated with the microwave applicator with slot antenna is depicted in Fig.1. A slot is cut on the outer conductor of a thin coaxial cable and the tip of the cable is the short-circuiting.

Here, L is the insertion depth, L1 is the length from antenna tip to center of slot, L2 is the width of the slot, $T_a$ is the external diameter of the applicator, $T_b$ is the diameter of the inserted antenna, and $T_c$ is the thickness of the catheter. The antenna is inserted into a catheter($\varepsilon_r$=2.6) made of poly tetra fluoro ethylene for hygiene.

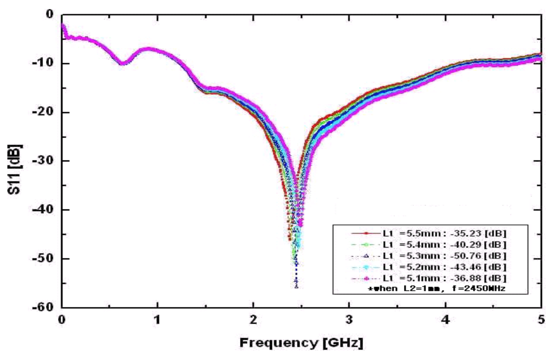


Fig.2 Optimization result of S11

We compare 2 parameters of the antenna, the length of L1 is varied so as to observe its effect of the resonance characteristics in the phantom. Fig.2 and Fig.3 show that increasing of L1 leads to lowering of the resonance frequency. The optimized $S_{11}$ is located between L1=5 and 6mm in case of L2=1 and L1=4mm, and 5mm in case of L2=2mm, respectively.

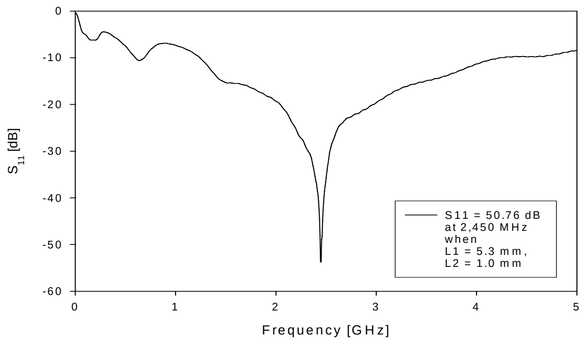


Fig.3 $S_{11}$ of applicator within tissue

Among the above results, to find the optimum resonance frequency as a function of L1 at 2.45 GHz, the L2 is set to 1 mm. The best results are shown in Fig.5 and Table 1.

Table 1. Parameters and results of optimization

| Parameters of antenna | results |
|---|---|
| $\varepsilon_{rp}$ (relative permittivity of liver) | 43.03 |
| $\sigma$ (conductivity of liver) | 1.69 S/m |
| *L* (insertion depth) | 70.0 mm |
| *L1* (length from slot to tip) | 5.3 mm |
| *L2* (slot width) | 1.0 mm |
| $S_{11}$ at 2.45 GHz | 50.7 dB |

Next, We compare the SAR distributions for validation of our calculation. Parameters of the human phantom and the antenna are the same as depicted in Table 1.

The phantom tissue of liver has almost the same electrical constants as those of human in the considered frequency, 2.45GHz. The applicator with one slot antenna is assumed to be inserted in a tissue of dimension 60mm*60mm*80mm.

In simulating the complete antenna, the electric field components are determined at the frequency of interest by a discrete Fourier transform of the time domain field behaviors.

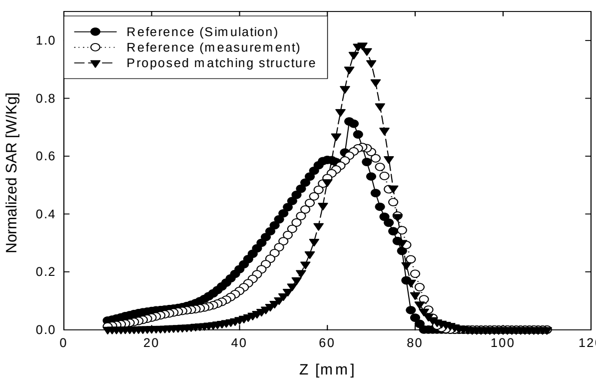


Fig.4 SAR comparison between the general applicator and the proposed matching applicator at 2.45GHz

The electric fields at the center of each cell are then evaluated by averaging the field components located at the cell sides, and the SAR distribution is evaluated as (1).

Fig.4 is the result for the SAR comparison. The validity of the simulation is checked by comparing the SAR distributions.

Table 2. Characteristics of the phantom and applicator dimensions for the comparison of temperature calculation simulation.

| | |
|---|---|
| Tissue type | Liver |
| Relative permittivity $\varepsilon_r$ | 43.03 |
| Conductivity $\sigma$ | 1.69 S/m |
| Volume | 60mm×60mm×60mm |
| Mass density | 1,060 kg/㎥ |
| Specific heat | 3,600 J/ kg·℃ |
| Thermal conductivity | 0.50 W/m·℃ |
| Applicator type | 3-slot sleeve |
| Frequency | 2.45 GHz |
| Insertion depth | 50.0 mm |
| L1 | 1.0 mm |
| L2 | 1.0 mm |
| L3 | 5.0 mm |
| L4 | 0.1 mm |

As seen in Fig.4, the newly designed applicator has much higher SAR distribution than the conventional slot antenna.

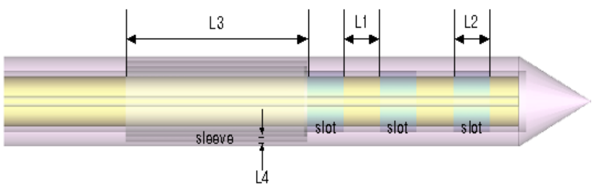


Fig.5 Schematic of 3-slot sleeve antenna

The microwave applicator, depicted in Fig.5, is a 3-slot and sleeve antenna mounted on an UT-34 flexible coaxial cable. The structure is realized by 3-slot cut on the outer conductor, the short circuiting of antenna tip and a cylindrical coaxial sleeve to the outer one.

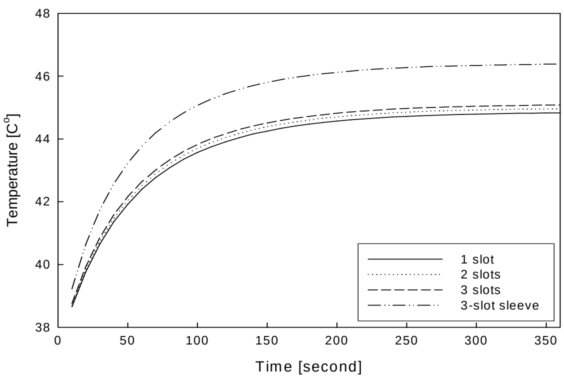


Fig. 6 Time course of maximum temperature increments about three different structures

The sleeve prevents current from coupling to the outer conductor and flowing back along the cable, thus confining power deposition in the region around the antenna tip.

The performance of the applicator is evaluated numerically by embedding the one in the human phantom tissue, which had a dimension of 60mm *60mm*60mm. The antenna tip is inserted to a depth of 50mm below the top of the phantom.

Fig.6 shows that the time behavior of the temperature increments for four different antenna structures at a radial distance of 3mm from the antenna axis at the level of the first slot. The temperature reaches steady state following an exponential behavior with a time constant of approximately 3~5 minutes.

From the above results, we may say that, for a tumor radius exceeding 20mm, new arrays made of more than 3 or 4 antennas are necessary.

# 4 Array

Using the antenna constructed in Section 3, the extension to 4-element antenna array will now be demonstrated. The radiating structure is assumed to be inserted in a liver phantom as depicted in Table 2.

In order to provide some clinical indications about the optimal geometry and input power for achieving an efficient tumor heating, the array geometry has also been studied from the thermal point-of-view by variation of the input power.

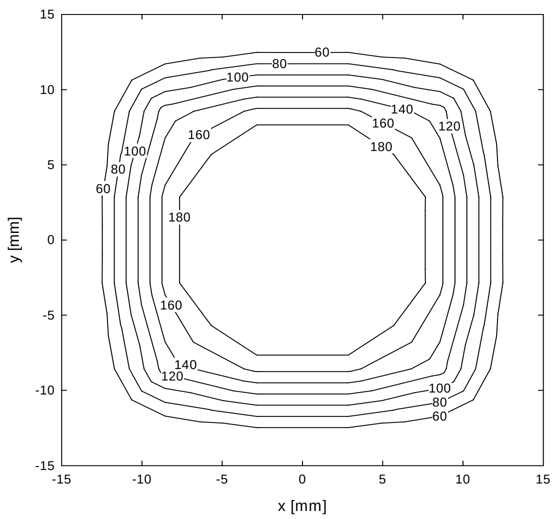


Fig.7 SAR contour plot on the *xy*-plane passing through the 4-applicator for 1 Watt of radiated power with 10 mm applicator spacing

Array made of four identical three-slot sleeve antennas placed at the vertices of a regular square of 10mm sides, respectively, have been studied.

Fig.7 shows the SAR contour over the *xy*-plane section passing through the first slot for a total power of 1.0 Watt. It shows that the power deposition is mainly concentrated in the region among the applicators.

In case of the proposed structure which has the three-slot and sleeve, the maximum temperature, therapy time, the area of therapy are higher and wider than the 1-slot applicator.

## 5 Conclusion

By using the impedance matching technique, we present the best resonance characteristics of applicator with coaxial slot configuration within phantom at 2.45GHz.

The SAR distribution due to the EM waves emitted from a temperature controlled ring slot antenna used for the hyperthermia therapy is calculated in liver, which has the relatively well localized heating performance in the phantom.

The result indicates an increase of heating effect by optimization of antenna dimensions. In case of the proposed structure which has a sleeve with slots, the maximum temperature, arrival time to steady state, and size of therapy are higher, faster, and wider than the applicator with one slot antenna.

But low power can't produce large lesion depth, even when the duration of the power radiation time is extended. From the results, we conclude the array structure is more effective than one applicator.

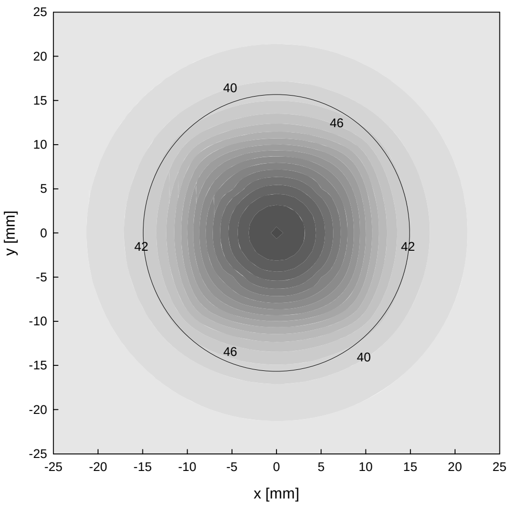


Fig.8 Temperature contour plot on the xy-plane passing through the first slot of the array applicator

The results of this study demonstrate that predicting thermal distribution is an reliable and accurate method, which can dynamically monitor the therapy effect in the three-dimensional region. It provides a theoretical and technical basis for controlling the size of the thermal field during the microwave interstitial treatment of cancerous tissue and reaches the aim of eliminating the tumor.

*References:*

[1] H. H. Pennes, Analysis of tissue and arterial blood temperatures in the resting human forearm, *J. AppL. Phys.*, Vol. 1, pp. 93-102, 1948.

[2] K. S. Yee, Numerical solution of initial boundary value problems involving Maxwell's equations in isotropic media, *IEEE Trans. Antennas Propagation*, Vol. 14, pp. 302-307, May. 1966.

[3] A. Winter, J. Laing, R. Paglione, and F. Sterzer, Microwave hyperthermia for brain tumors, *Neurosurgery*, Vol. 17, No. 3, pp.387-399, 1985.

[4] C. H. Durney and M. F. Iskander, *Antenna handbook*, *Antennas for Medical Applications*. New York: Van Nostrand, 1988, ch. 24.

[5] American National Standard Safety Levels with Respect to Exposure to Radio Frequency Electromagnetic Fields, 3 kHz to 300 GHz, *ANSI/IEEEC* 95.1-1992.

[6] R. D. Nevels, G. D. Arndt, G. W. Raffoul, and A. Pacifico, Microwave catheter design, *IEEE Trans. Biomed. Eng.*, Vol. 45, pp. 885-890, July 1998.

[7] A. Rosen, M. A. Stuchly, and A. V. Vorst, Applications of RF/microwaves in medicine, *IEEE Trans. Microwave Theory Tech.*, Vol. 50, pp. 963-974, Mar. 2002.