Theoretical Study of the Power Distributions for Interstitial Microwave Hyperthermia

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Abstract: - Reliable information on the heat distribution inside biological tissues is necessary for the planning and optimization of experiments. In order to obtain the electromagnetic field and heat inside biological tissues for interstitial microwave hyperthermia, it is important to know the relation between antenna parameters and biological tissues. This paper emphasizes on the effect of tissue and antenna parameters on electric field and absorbed power in biological tissues.

Key-Words: - Interstitial microwave hyperthermia, power distribution, tissue parameters, antenna parameters, microstrip antenna, theoretical study.

1 Introduction

The sensitivity of biological tissues to heat has become a prevalent technique for cancer tumor treatment. The heat can be generated in the biological tissues by electromagnetic wave.

The determination of the electromagnetic absorption inside biological tissues is usually expressed in terms of the Specific Absorption Rate (SAR). Theoretical studies of the SAR in biological models have been of increasing interest in recent years. However, it is still an extremely problematical and challenging scientific mission. A quite large amount of literature on heating up the tissues is available in the area of hyperthermia studies [1]-[4].

There are different methods to measuring theSAR [4]:

- To measure the electric field inside the tissue, and then to calculate the SAR.
- To measure the temperature change due to the heat product by the radiation, and then to calculate the SAR.
- To calculate the absorbed power as the difference between incident power and scattered power, and then to calculate the SAR.

In this paper, we concentrated exclusively on the relations between biological parameters and antenna parameters.

2 Problem Formulation

The SAR value at a point of a material exposed to the electromagnetic field can be directly determined through E-field strength. The dielectric constant and the conductivity of the tissue determine the strength and distribution of the electric field that penetrates into the tissue.

Fig.1 shows the injected catheter applied to a tissue for interstitial microwave hyperthermia.

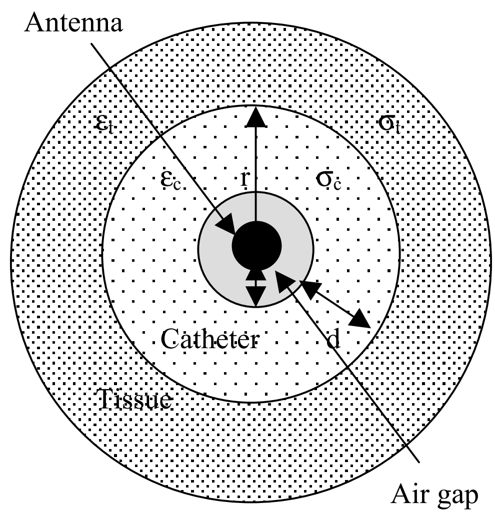

Fig. 1- The general model of injected catheter to a tissue.

The catheter is a kind of dielectric with dielectric constant ε_c and thickness d. An antenna is placed inside the catheter with an air layer gap between antenna surface and catheter wall. The biological tissue parameters, which have been used in this study are dielectric constant ε_t and conductivity σ_t. A model for calculation of propagation of electromagnetic wave is shown in Fig.2.

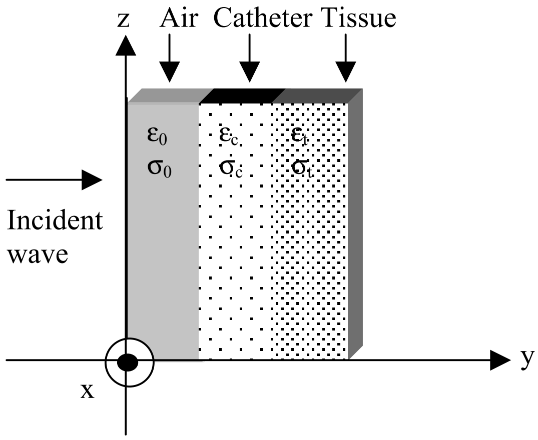

Fig. 2. Calculation model of the interstitial microwave hyperthermia.

2.1 Catheter dielectric properties

There are different types of dielectrics, which have been used for catheter. In case of interstitial hyperthermia a catheter dielectric constant should be relatively independent of frequency and temperature, while the dielectric losses are low. Moreover it has to be sufficient strength to be formed as thin as possible with respect to the applications.

If the catheter wall thickness is sufficiently thin, and dielectric losses are low, then one can ignore the losses of radiated power from antenna through the catheter. Therefore, power at outer catheter wall will be considered same as radiated power from antenna.

2.2 Type of antenna

During the last decade the microwave antennas designed for hyperthermia have been changed significantly from bulky antenna to printed patch radiator.

From premature applications of stainless-steel needles for interstitial hyperthermia, experience directed to the detection of a number of limitations and problems. To solve some of the limitations coupled with the use of stainless-steel needles, a number of designings have been developed with solid and hollow electrode, shielded partially or totally with catheter. Also the coaxial type antennas with different methods to control the heat have been developed [5], [6].

In this paper we used rectangular microstrip antenna for further calculation, because of all advantages which this antenna can provides. The antenna's designing has not been discussed.

2.3 Electromagnetic performance

In order to analyze the wave propagation in the nonuniform medium, it is stratified by the model to different layers as it is shown in Fig. 2. The dielectric permittivity of each layer may vary as a function of heat [7]-[9], and it depends on the microwave frequency, too.

The absorbed power P per unit volume in biological tissues because of exposure to electric field is given by

$$P = \frac{\sigma E^2}{2} \tag{1}$$

Where σ Sm^{-1} is the electrical conductivity of the medium and E Vm^{-1} is the maximum electric field. A related quantity is the absorbed power per unit mass (SAR), which is *P* divided by the density of the material.

In general one can consider the whole body as a big biological tissue for interstitial hyperthermia. In this case due to small penetration depth at frequency of 5800 MHz (δ = 7.5 mm [10]) the electric field distribution in the tissues can be calculated in the same way as for the distribution within a semi-infinite medium [11]. Therefore,

$$E(y) = E_0\, e^{-y/\delta} \tag{2}$$

Where E(y) is the electric field on y direction at distance y from antenna and δ is the penetration depth.

As mentioned above, the radiated element is a rectangular microstrip antenna. Calculation of electric field for a rectangular microstrip antenna can be found in [12]. Consider a rectangular microstrip antenna that radiates an electromagnetic field that has both an E_x and an E_y components of electric field along the z axis as shown in Fig. 3.

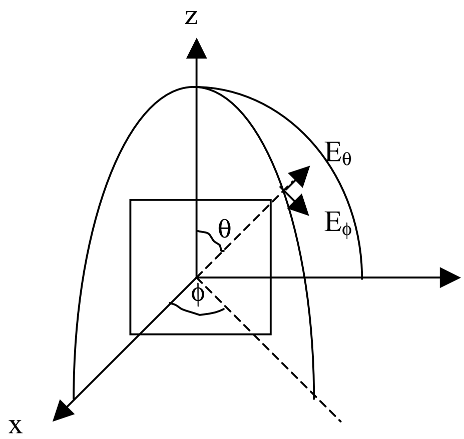

Fig. 3. Illustration of field components radiated by an antenna.

The total electric field is,

$$E = (E_x^2 + E_y^2)^{1/2} \quad (3)$$

Where

$$E_x = E_\theta \cos\theta - E_\phi \sin\theta \quad (4)$$

$$E_y = E_\theta \sin\theta + E_\phi \cos\theta \quad (5)$$

Where E_x and E_y are cross and co-polarized fields respectively. The power radiated in the cross-polarized filed is wasted, and this reduce the effective gain of the system.

The polarization of a rectangular microstrip antenna is linear and directed along the resonating dimension. The cross-polarized field can be minimized by suitable choice of patch width and substrate thickness.

The cross-polarized field will be zero, when,

$$E_\theta \cos\theta = E_\phi \sin\theta \quad (6)$$

Therefore, resulting from (3) and (5)

$$E = E_\theta \sin\theta + E_\phi \cos\theta \quad (7)$$

When the thickness of the catheter wall sufficiently thin, and dielectric losses are low , electric field distribution can be rewritten as,

$$E(y) = (E_\theta \sin\theta + E_\phi \cos\theta)\, e^{-y/\delta} \quad (8)$$

At y = 0, E(y) is the electric field strength on the catheter outer wall in distance r from antenna. Fig. 4 shows the radiation from catheter to biological tissue.

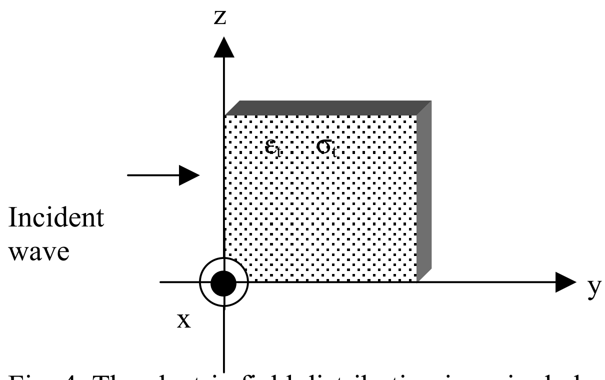

Fig. 4. The electric field distribution in a single layer (tissue) with radiation from catheter wall.

From Equation (1), the absorbed power per unit volume at any distance from catheter wall in biological tissue will be,

$$P = \frac{\sigma_t}{2} (E_\theta \sin\theta + E_\phi \cos\theta)^2 e^{-2y/\delta} \quad (9)$$

3 Results and Conclusion

For this study a rectangular microstrip antenna has been used as radiating elements. The procedure for antenna designing has not been discussed. There are a number of papers, which discussed the microstrip antenna designing with different shapes. The rectangular microstrip antenna parameters at resonant frequency of 5800 MHz is shown in Table.1 [13].

Table 1. Antenna parameters at frequency 5800 MHz.

Resonant frequency	5800 MHz
Radiation resistance	500 Ω
Bandwidth	48.14 MHz
Patch length	7.8 mm
Patch width	6.2 mm
Thickness of substrate	0.1 mm
Dielectric constant	11.7
Directivity	5.28 dB
VSWR	2:1

Calculated E and H- planes of antenna with respect to Table 1, at frequency of 5800 MHz in different angles (θ^o) are shown in Fig. 5 and Fig. 6.

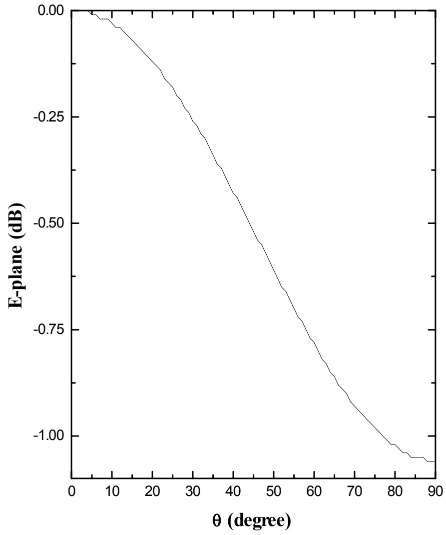

Fig. 5. Calculated E_θ pattern at 5800 MHz.

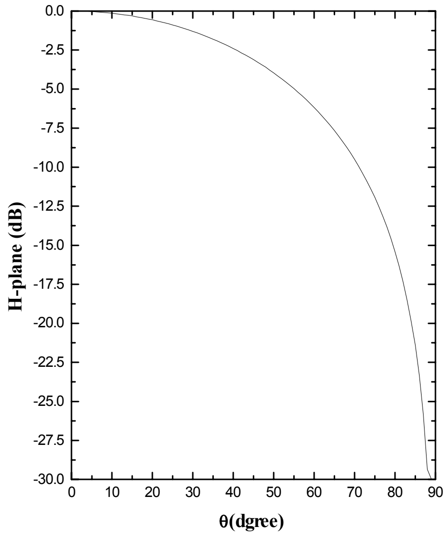

Fig. 6. Calculated E_ϕ pattern at 5800 MHz.

The electrical properties of different tissues at frequency of 5800 MHz is summarized in Table 2.

Table 2. Electrical properties of the media at 5800 MHz [10].

	δ(mm)	ε_r	σ(Sm^{-1})
Muscle	48.485	4.9615	7.5
Colon	48.456	5.5701	6.7
Prostate	52.213	5.9478	6.5
Tongue	47.806	5.2350	7.1

ε_r Relative permittivity
σ: Conductivity
δ: Penetration

Using parameters value from Tables 1 and 2, and chosen electric field amplitude E = 10 V/m, from the Equation (9) absorbed power per unit volume is shown in Fig. 7.

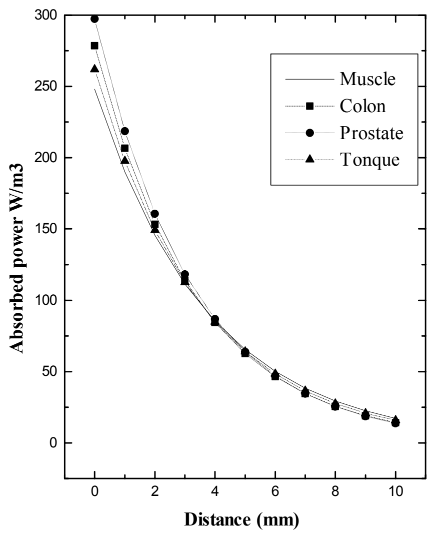

Fig. 7. Absorbed power at 5800 MHz on different tissues for E = 10 V/m.

The antenna thickness and width of patch, radiation resistance, distance to tumor and polarization give the value of the amplitude of electric field inside a tumor. Fig. 7 is shown for different tissues, need a different power density to avoid tissue burning at contact point of catheter and tissue for interstitial microwave hyperthermia, if same antenna is going to be use for different tissues.

Acknowledgments

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