Design and Simulation of Hyperthermia Antenna

Vibhav Singh

Dept. of Electronics and Communication, SRM University, Tamil Nadu, India

Abstract
This paper proposes the design and simulation of a rectangular microstrip patch antenna for hyperthermia applications. Using electromagnetic simulations we optimized the dimensions of a probe-fed patch antenna design for operation at 2.45 GHz. This antenna is having the thickness of 1.6mm FR-4 substrate, is a probe feed and has a full ground plane. It has been used as hyperthermia applicators in the treatment of cancerous human cell satsuperficial depths inside the body. On the basis of the study at 2.45GHz, we anticipate good central interference of the fields of multiple antennas and conclude that this patch antenna design is very suitable for the clinical antenna array. Simulation results for antenna design optimization is carried out using Ansys HFSS. The design and the results are shown and discussed in this paper.

Keywords
Applicators, Cancer, Human Cell, Hyperthermia, Patch Antenna

I. Introduction
Hyperthermia (also called thermal therapy or thermotherapy) is a type of cancer treatment in which body tissue is exposed to high temperatures (up to 113°F). This technique is also used in chemotherapy and radiotherapy, as well as in some physiotherapeutic pathways and other diseases [1]. Hyperthermia require not only a suitable energy source for heat production but an understanding of the underlying pathophysiological condition being treated to define the critical target tissue temperature and the ability of the therapeutic EM energy to reach the target tissue [2]. The transfer of electromagnetic energy into target body region of injured muscle tissue is used by effectiveness of Radio-Frequency (RF) Hyperthermia treatment system. Due to efficient heating capabilities and the possibility of energy transfer without invasive procedures, the antennas possess some special characteristics for hyperthermia. The patch antennas are characterized by a larger number of physical parameters than conventional microwave antennas. They can be designed to have many geometrical shapes and dimensions but rectangular Microstrip resonant patches have been used extensively in many applications [3].

Here, we designed and analyzed a patch antenna specially for hyperthermia, focusing mainly on its SAR characteristic. The patch antennas are characterized by a larger number of physical parameters than conventional microwave antennas. Thus, the design and analysis of the patch antenna are crucial for hyperthermia. The numerical model consists of a rectangular-type metal patch on a dielectric substrate of height h and permittivity εs fed by a coaxial probe with feed position (Xg, Yg) defined with respect to patch corner and irradiating a 50 mm thick rectangular muscle tissue. The patch is located in a rectangle metal patch to minimize its sensitivity to variation in tissue load and surrounding environment.

II. Methodology
The use of an antenna design within a Hyperthermia (HT) applicator leads to some application specific requirements [5]. As the antenna is to be embedded in a movable applicator system, hence the antenna must be light, small, and robust. Because at fat-muscle transitions, the E-field components perpendicular to the patient skin lead to high power absorption values.

A. 3D Numerical Model
The numerical model consists of a rectangular-type metal patch on a dielectric substrate of height h and permittivity εs fed by a coaxial probe with feed position (Xg, Yg) defined with respect to patch corner and irradiating a 50 mm thick rectangular muscle tissue. The patch is located in a rectangle metal patch to minimize its sensitivity to variation in tissue load and surrounding environment.

B. Patch Antenna Design
For hyperthermia treatment fig. 1 shows the microstrip patch applicator at 2.45 GHz. For reducing the size of patch antenna a low loss high permittivity substrate was chosen at 2.45 GHz. Reactive loading of the patch further reduced by reactive loading of the patch using shorting pin. The dimensions of the rectangular-type patch, substrate (h), and feed position (Xg, Yg) were optimized for resonance at 2.45 GHz. The 3D model of the applicator with rectangle-type patch was designed using, Ansys HFSS. Table 1 lists the electrical properties used in the numerical simulations. The time harmonic vector electric field calculated by HFSS is used to compute specific absorption rate (SAR), σ|E| ² / 2ρ where σ is tissue conductivity and ρ is tissue density [4]. Properties of copper were given for metal structure in the patch applicator and coaxial feed connector. Using wave port option in HFSS coaxial feed of the patch antenna was excited.

Several parametric sweeps were carried out on the length, width, and height of the patch, feed position, muscle thickness, substrate height and muscle height for resonance at 2.45 GHz.

Table 1: Electrical Properties of Model Domain

<table>
<thead>
<tr>
<th>s.no</th>
<th>Materials</th>
<th>Relative permittivity</th>
<th>Conductivity (S/m)</th>
<th>Loss Tangent</th>
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<td>Substrate</td>
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<td>5</td>
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<td>1</td>
<td>1e+03</td>
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</tr>
<tr>
<td>6</td>
<td>Vacuum</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

III. Physical Parameters of the Antenna
The antenna parameters of this antenna can be calculated by the transmission line method (Balanis, 2005), as given below.

A. Width of the Patch
The antenna width can be determined by (James et al, 1989)

\[ W = \frac{c}{2f_0 \sqrt{\frac{\varepsilon_r + 1}{2}}} \]  \hspace{1cm} (1)

B. Length of the Patch
The effective constant can be obtained by (Pozar et al, 1995)

\[ \varepsilon_{reff} = \frac{\varepsilon_r \varepsilon_{eff}}{\varepsilon_r + \varepsilon_{eff}} (1 + \frac{h}{w}) \]  \hspace{1cm} (2)

Where:
- \( W \) = Width of the patch
- \( \varepsilon_{reff} \) = Effective dielectric constant
- \( \varepsilon_r \) = Dielectric constant of substrate
- \( h \) = Height of dielectric substrate
- \( \varepsilon_{eff} \) = Effective dielectric constant
The dimensions of the patch along its length have now been extended on each end by a distance $\Delta L$, which is given empirically by (Ramesh et al, 2001):

$$\Delta L = 0.412h \left( \frac{\varepsilon_{\text{eff}} + 0.3 \left( \frac{L}{h} + 0.264 \right)}{\varepsilon_{\text{eff}} - 0.3 \left( \frac{W}{h} + 0.8 \right)} \right)$$  \hspace{1cm} (3)

The actual length $L$ of the patch is given as (Pozar et al, 1995):

$$L = \frac{\lambda_0}{2} - 2\Delta L$$  \hspace{1cm} (4)

C. Feed Location Design

The position of the coaxial cable can be obtained by using (Dr. Max Amman):

$$X_f = \frac{L}{2\sqrt{\varepsilon_{\text{eff}}}}$$  \hspace{1cm} (5)

Where $X_f$ is the desired input impedance to match the coaxial cable and $\varepsilon_{\text{eff}}$ is the effective dielectric constant.

$$Y_f = \frac{W}{2}$$  \hspace{1cm} (6)

D. Ground Dimension

For practical considerations, if the size of the ground plane is greater than the patch dimensions by approximately six times the substrate thickness all around the periphery it is essential to have a finite ground plane. Hence, the ground plane dimensions would be given as (Huang, 1983) (Thomas, 2005):

$$L_g = 6h + L$$  \hspace{1cm} (7)

$$W_g = 6h + W$$  \hspace{1cm} (8)

E. Antenna Parameters

Length = 40.4 mm  \hspace{1cm} (9)

Width = 27.25 mm  \hspace{1cm} (10)

$L_g = 69.3447$ mm  \hspace{1cm} (11)

$W_g = 46.855$ mm  \hspace{12}

$X_{g, f} = -10.145$ mm  \hspace{1cm} (12)

$Y_{g, f} = -5.87$ mm  \hspace{1cm} (13)

IV. Results and Discussion

The antenna return loss over 2.45 GHz is shown in Fig. 1. From Fig. 1a we observe that as the height between antenna and muscle increases the resonance shifts to higher frequencies. From Fig. 1b at height of 6mm between antenna and muscle we observe the resonance of antenna. To get the resonance at 2.45 GHz antenna length was fixed at 69.3447 mm. For fabrication following were optimal antenna dimensions and feed position. Thus, the optimal design of the rectangle-type patch was fixed as $L = 40.40$ mm, $L_g = 69.3447$ mm, $W = 27.25$ mm, $W_g = 46.855$ mm, $X_f = -10.145$ mm, $Y_f = -5.87$ mm ($h = 1.6$ mm, $p = 6$ mm ( $p$ = Distance between the patch and muscle). The antenna is less susceptible to external environment as the antenna have metal cavity. Fig. 1(c) shows the simulated normalized local (SAR) for the optimized rectangle-type applicator calculated at varying depth in the muscle tissue. The SAR pattern is normalized with respect to the maximum value recorded in the measurement planes.

The parameters for inhomogeneous body tissues are defined [6] and whole-body electromagnetic phantoms with highly resolved and detailed subterranean geometries [7-8] exist for in-silico analysis. A tri-layered tissue model was used to minimize computational resources and for clarity. For all body regions, the skin thickness ranges from minima at the thorax, abdomen, spine and limbs in children to maxima at the adult thorax [9]. To accommodate a muscle the designed antenna was fabricated. The dimensions of the fabricated muscle are 80mm length and 80 mm breadth and 50mm height. The given Fig show the radiation pattern of rectangle-patch antenna.

Fig. 1(a): Variation of Resonance With Distance Between Height of Antenna and Muscle

Fig. 1(b): Resonance of Antenna at the Height of 6mm

Fig. 1(c): Normalised Local SAR

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Fig. 2(a): Show The Radiation Pattern of Rectangle-Patch Antenna
V. Conclusion
For the treatment of superficial cancer cells the performance of a new compact-microstrip patch antenna has been described. The size of the radiating patch is significantly reduced using high dielectric substrate and reactive loading with shorting pin. It also has low-cost, ease of manufacture and low profile advantages over other waveguide and horn applicators. The geometric parameters are optimized for size reduction, high SAR, frequency detuning stability and a matched input-impedance bandwidth.

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Reference

VIBHAV SINGH was born in India and currently pursuing his B.Tech (Electronics and Communication) from SRM University, India. He is working on antennas.