Numerical Analysis of an Applicator for Hyperthermia Treatment of Melanoma

J. L. Duque Muñoz
Dept. of Electrical Engineering
Universidad Nacional de Colombia
Bogotá D.C., Colombia
jlduquem@unal.edu.co

N. García Ramirez
Dept. of Electrical Engineering
Universidad Nacional de Colombia
Bogotá D.C., Colombia
nigarciara@unal.edu.co

J. L. Araque Quijano
Dept. of Electrical Engineering
Universidad Nacional de Colombia
Bogotá D.C., Colombia
jlaraqueq@unal.edu.co

***Abstract*—This document presents the design and validation of an applicator conceived for hyperthermia treatment of the melanoma in the human male torso and female leg. The applicator consists of an antenna array operating in the 5.8GHz ISM band immersed in an interface layer. The resulting device is comfortable to wear by the patient, low-cost and easy to store and handle. Simulation is carried out using Sim4Life and the ViP 3.0 human model, and the results demonstrate correct energy delivery to the tissue under treatment.**

***Index Terms*—Cancer, hyperthermia, melanoma, multi-physics Sim4Life, simulation, tissue.**

I. INTRODUCTION

Hyperthermia is a therapy for the treatment of tumors that operates by raising the temperature of affected tissue above the body average temperature in a selective manner, typically in the range 42°C-45°C. By combining hyperthermia with radiotherapy and chemotherapy, the effectiveness of these conventional treatments may reach five-fold and ten-fold improvements respectively [1]. Nonetheless, hyperthermia is still under scrutiny as there is no evidence that it induces increased survival rates, while side effects such as burns, blisters, pain and nausea have been reported [2].

In order to improve the effectiveness of hyperthermia and avoid its negative side effects, several works have been carried out recently. In [3] it is presented an improvement to the magnetic heat induction technique consisting in the insertion of nanoparticles in the affected tissue. The work in [4] proposes a metamaterial structure operating at the 2.4GHz ISM band to improve focusing of electromagnetic energy in the zone of interest. At lower frequencies, [5] propose a metamaterial antenna array at 434 MHz to heat uniformly tissue areas of considerable size. In [6], the FDTD method is used to evaluate the temperature increase induced by the electromagnetic field with a graded grid for improved accuracy in the geometrical representation.

The work in [7] presents a realistic model of space-dependent blood perfusion in a multi-physics simulation to understand the perfusion features of the tumor, with a circular patch antenna with slotted ground operating at 434 MHz as applicator. In [8] the authors design an applicator for hyperthermia treatment specifically targeted at not causing the patient any pain, using a transmitarray lens and a distilled water interface. [9] proposes a 3-D antenna array operating at 4.2GHz for the treatment of breast cancer that avoids hot spots outside the treated area.

Throughout the literature revised we see a variation of: applicator type (antenna), interface layer, illness targeted, tissue location, level of detail anatomical model. In this work, we present the design and numerical validation of an antenna array applicator for hyperthermia treatment of melanoma that is compact, robust in view that antennas are immersed on a solid interface layer and cost-effective thanks to a simple design. The validation process considers a detailed model of the affected zone and its environment within the body to assess the performance in terms of energy focusing and power delivery. The computation is carried out with Sim4Life [10], and results in quantitative data that provide a very accurate prediction of the performance.

II. SIMULATION SCENARIO AND APPLICATOR DESIGN

The anatomical model employed is extracted from the Virtual Population (ViP 3.0) [11], which is a group of computable human models that describe the multi-physics and physio- logical behavior of body tissues with great accuracy in high resolution, and allow postural manipulation. In the anatomical model employed, no differentiation in tissue characteristics for healthy/ill tissue is analyzed.

The applicator consists of a planar antenna array operating in the 5.8GHz ISM band, designed to attain energy focusing in the zone of interest and low return loss. An interface layer favors energy delivery to the affected tissue by avoiding the free-space/body impedance mismatch and preventing the generation of hot spots in or near the body, thus preventing discomfort and unintended tissue heating, while favoring focusing for better control of the temperature profile. The resulting design is compact, such that the patient can wear it comfortably, and robust in view that the 3D radiating structures are backed by a ground plane and are embedded in a solid dielectric interface medium. The elemental radiators are elevated patch antennas fed with an L-feed, which are directive and very broadband (even more so thanks to the 2x2 broadside array configuration), hence making the device robust against patient-to-patient variations. Furthermore, the ground plane prevents radiation in unwanted directions and provides a solid support for connector/handles to operate the device. The details of this design are illustrated in Fig. 1.

Submitted On: August 29, 2020
Accepted On: September 5, 2020
https://doi.org/10.47037/2020.ACES.J.351130

The array applicator is embedded in an interface with transverse dimensions 15cm x 15cm and height 10 cm. In order to minimize reflections with actual tissue, this material is chosen with parameters very similar to muscle: dielectric constant 48.4846 and loss tangent 0.0227.

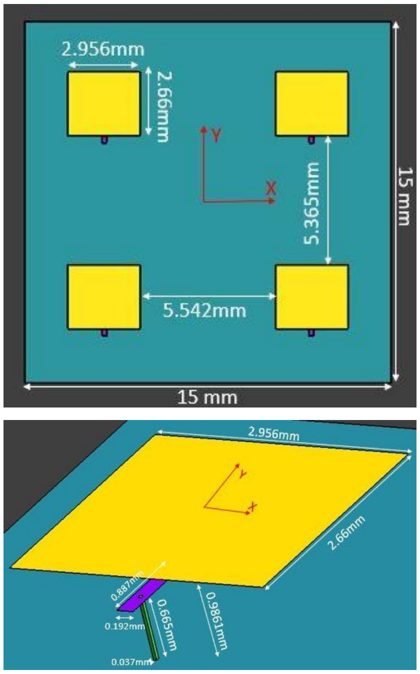

Fig. 1. Detail of the antenna array used as applicator.

III. Results

We report results on the initial validation of the applicator, as shown in Fig. 2 in the form of cuts of the Specific Absorption Rate (SAR) in three orthogonal cuts inside the interface. The first aspect to notice from the first two cuts in Fig. 2 is the favorable role played by the interface, that buffers the unfavorable field distribution present near the array elements (broad and multiple high-intensity lobes). It is clear from the last cut in Fig. 2 that 9cm above the ground plane, near the end of the interface, the field distribution is well suited for the treatment of melanoma (3dB diameter of about 2cm).

Acknowledgment

This work was possible by a Sim4Life for Science License granted by ZMT [10].

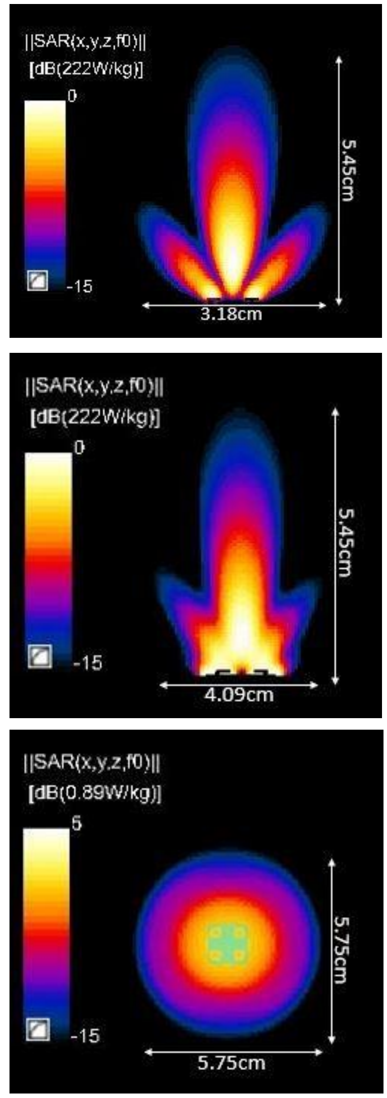

Fig. 2. SAR results for three orthogonal cuts: XZ (top), YZ (center) and XY, 9cm above the ground plane (bottom).

References

[1] J. van der Zee, "Heating the patient: A promising approach?," Annals of Oncology, vol. 13, no. 8, pp. 1173-1184, 2002.
[2] "Hyperthermia in Cancer Treatment," National Cancer Institute. [Online]. Available in: https://www.cancer.gov/about- cancer/treatment/ types/surgery/hyperthermia-fact-sheet
[3] L. Zhang, Y. Du, and D. Wu, "FDTD simulation of magnetic heat induction on Human Body Subject," ACES Conference Paper, 2015.
[4] Y. Gong and G. Wang, "Superficial tumor hyperthermia with flat left-handed metamerial lens," Progress in Electromagnetic Research, PIER 98, 389-405, 2009.
[5] D. Vrba, D. B. Rodriguez, J. Vrba, and P. R. Stauffer, "Metamaterial antenna arrays for improved uniformity of microwave hyperthermia treatments," Progress in Electromagnetic Research, vol. 156, 1-12, 2016.
[6] N. Chavannes, E. Neufeld, and N. Kuster, "Recent Advances in Biomedical Modeling: Hyperthermia Treatment Planning," 23rd Annual Review of Progress in Applied Computational Electromagnetics, Mar. 19-23, 2007 - Verona, Italy, 2007, ACES.
[7] G. Muntoni, A. Fanti, G. Montisci, and M. Muntoni, "A blood perfusion model of a RMS tumor in a local hyperthermia multi-physic scenario: A preliminary study," IEEE Journal of Electromagnetics, RF, and Microwaves in Medicine, vol. 3, no. 1, pp. 71-78, Mar. 2019.
[8] W. C. Choi, S. Lim, and Y. J. Yoon, "Design of noninvasive hyperthermia system using transmit-array lens antenna configuration," IEEE Antennas and Wireless Propagation Letters, vol. 15, pp. 857-860, 2016.
[9] P. T. Nguyen, A. Abbosh, and S. Crozier, "Three-Dimensional Microwave Hyperthermia for Breast Cancer Treatment in a Realistic Environment Using Particle Swarm Optimization," IEEE Transactions on Biomedical Engineering, vol. 64, no. 6, pp. 1335-1344, June 2017.
[10] Sim4Life by ZMT, www.zurichmedtech.com
[11] https://itis.swiss/virtual-population/virtual-population/vip3/