A Compact Antenna for Microwave Imaging and Hyperthermia Treatment of Brain Tumor

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Abstract— **This paper presents a design of a small size antenna in the L-band for applications of microwave hyperthermia treatment and microwave imaging of the human head. The design is intended to provide an increase of the power radiated toward the human and concentrate the specific absorption rate (SAR) values in the tumor tissue. Size reduction is achieved here by adding a high dielectric layer just above the antenna, and the best suitable material for this application is found to be the fresh water. The design depends on a short circuit triangular slotted shaped on a thick foam substrate to enhance its bandwidth. Analysis is performed using the IE3D and SEMCAD-X simulators, and the obtained overall antenna size is $40 \times 40 \times 14$ mm^3. The resonance frequency in air is 2.35 GHz at free space, which is reduced near the head to 1.4 GHz, using a 5-mm water layer pad. Simulation analysis is provided of the SAR patterns associated with this antenna.**

Keywords-Hyperthermia Treatment; Microwave Imaging; Antennas

I. INTRODUCTION

Application of microwave energy in the imaging and treatment of tumors is currently gaining interest by the research community. In terms of imaging, microwave based techniques do not offer the capabilities of advanced biomedical imaging systems such as the magnetic resonance imaging (MRI). However, microwave imaging systems have the potential of being simple, portable and cost-effective.

Electromagnetic EM energy can also be used in the hyperthermia treatment plans by depositing the energy into the tumors in order to increase the local temperature and eventually eliminate or reduce these tumors. Hyperthermia is typically designed to elevate the tissue temperature to values between 40-44°C [1]. High temperatures (42°C-45°C) is known to ruin the protein build of cancerous cells and thus improve local tumor control by changing the cell construction and even killing these cells [2]. Hyperthermia treatment is simpler and safer compared to chemotherapy or radiotherapy. The challenges related to effective focus of the EM energy, however, still hinder the wide acceptance of this approach [3].

Design techniques have been provided to make use of antenna arrays to enhance the focus of the EM energy into the locality of the tumors. Antenna arrays are effective to capture the scattered EM field, which can be analyzed to solve the inverse problem and obtain the constructed images of the tissues. The performance of antenna arrays in imaging and treatment can be enhanced by increasing the number of implemented elements. However, for imaging and treatment of brain tumor, the available space around the head is limited and interest should be directed to reduce element size. Reducing antenna size allows the use of an array with enough number of elements to focus power into the head for hyperthermia treatment, while collecting substantial part of the reflected radiation for imaging purpose.

Small size antennas in L-band have received much attention for handset wireless applications. One of the most important design objectives of these antennas is to minimize the power absorption in the human head, by reducing the specific absorption rate (SAR). In this case, the antenna performance, especially the matching parameter (S11) should have minimum effect by the human body [4]. On the other hand, inverting the antenna performance by increasing SAR values provides a useful tool in new applications related to microwave imaging and hyperthermia treatment of brain tumors. The objective is to increase the power radiated toward the human and concentrate the SAR values in the tumor. The challenge is to design physically small size antennas that are operable at low frequency with sufficient penetration.

The size reduction is achieved here by adding a high dielectric layer just above the antenna. The most suitable material for this application is found to be the fresh water. The developed antenna is a short circuit triangular slotted shaped on a thick foam substrate to enhance its bandwidth. The antenna is analyzed using IE3D and SEMCAD-X simulators [5] and [6], and the overall antenna size is $40 \times 40 \times 14$ mm^3. The resonance frequency of the antenna in air is 2.35 GHz at free space. To reduce the antenna resonance frequency, a 5-mm water layer with dielectric constant of 80 is inserted just above the patch. The resonance frequency reduces to 1.4 GHz when adding a 30-mm layer

simulating the human tissue with 40 dielectric constant and 1 s/m conductivity. The resonance frequency in this case is almost not affected, and this is an important practical notice that allows to tune the antenna once at the design stage with the presence of the water layer.

II. ANTENNA GEOMETRY AND RETURN LOSS CALCULATION

Microstrip antennas have the attractive features of low profile, small size, and low cost. The size of conventional microstrip antennas is still large, especially at the lower microwave range. The size of conventional microstrip antennas can be reduced in various ways such as: (1) the use of high dielectric constant substrate, (2) the use of reactive loading, (3) the shaping of conventional patch structures by cutting slots or slits in the radiating patch or (4) any combination of these techniques. Microstrip antennas are usually narrow band and become unsuitable for many applications. One of the most important structures that maintain reasonable small size and simultaneously increase the bandwidth is the planar inverted-F antenna (PIFA) [7-**Error! Reference source not found.**11].

The proposed antenna structure is shown in Fig. 1. The triangular shape is selected because it has almost similar radiation pattern as the rectangular shape with smaller size. The antenna consists of two layers. The first layer is foam of 12.5 mm thickness. The second layer is a Duroid of 2.2 dielectric constant and 1.57 mm thickness. This layer is used to simplify the implementation. The physical parameters are shown in the figure. The antenna is fed by a coaxial probe at the centerline of the patch, at 5 mm away from the tip of the triangle as shown in the figure. A shorting wall of 14 mm width is located at the edge of the patch to connect the triangle to the ground and so reduce the antenna size.

The antenna is first simulated with and without the slots using the IE3D software [5]. The simulation result is shown in Fig. 2. It is shown that the antenna resonance frequency decreases by etching one or more slots in appropriate positions. However, the resonance frequency can be decreased more by adding a fresh water layer just above the triangular patch. Figure 3 shows the reduction of the resonance frequency when 5 mm fresh water layer is added just above triangular patch. Human brain equivalent layer of 30 mm thickness is also added above the fresh water pad.

Simulation is then performed using SEMCAD X environment [6]. The antenna is simulated with and without slots. It is noticed from the analysis that, the effect of the slots is almost negligible when a high dielectric constant water pad is added. Therefore, the main size reduction in this configuration is achieved by the fresh water pad added just above the triangular patch. The effect of the etched slots in the triangular patch on the field distribution and thus the SAR values inside the human brain, considering the presence of a brain tumor is investigated in the next section
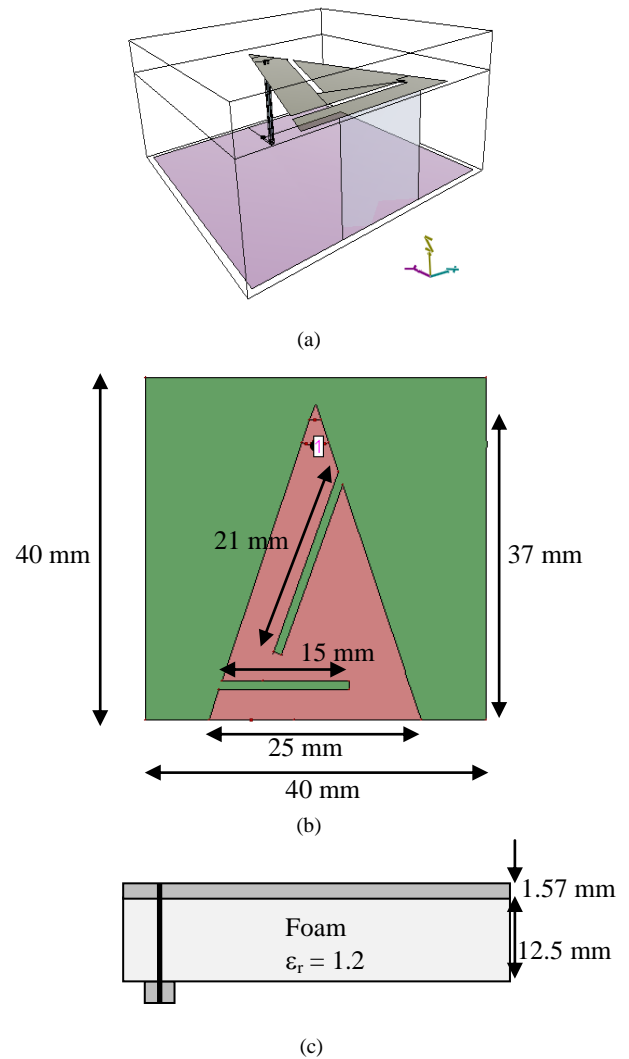

(a)

(b)

(c)

Figure 1.   Geometry of the proposed antenna. (a) 3D view (b) Top view, and (c) side view.
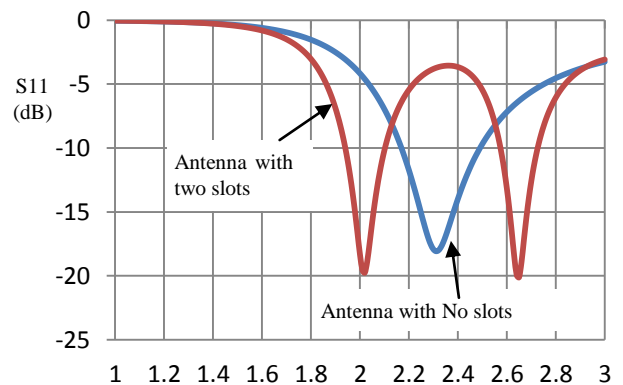

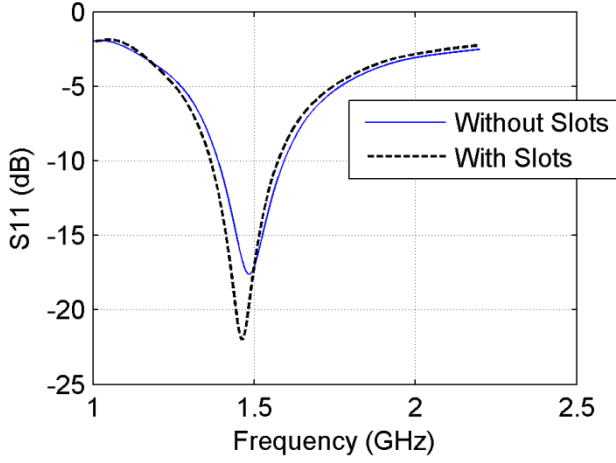Figure 2.   Simulated S11 of the antenna shown in Fig. 1 with and without slots.

Figure 3. The simulated S11 of the antenna with the 5-mm fresh water pad added just above the patch, and human brain equivalent layer of 30-mm. The antenna is simulated with and without slots.

III. SAR CALCULATION IN THE HUMAN BRAIN

Specific absorption rate or SAR is absorbed dose rate and it is thus the time derivative of the incremental energy (dW) absorbed by or dissipated in an incremental mass (dm) contained in a volume (dV) of a given density (ρ):

$$SAR = \frac{d}{dt}\left(\frac{dW}{dm}\right) = \frac{d}{dt}\left(\frac{dW}{\rho dv}\right) \tag{1}$$

SAR can be measured by recording the local temperature values. SAR is proportional to temperature increase if the effects of heat diffusion can be neglected [12]. Another way of determining the SAR is by measuring the electric field (**E**) inside the tissue-simulating material. SAR will be given in terms of conductivity σ and density ρ as

$$SAR = \frac{\sigma|\mathbf{E}|^2}{\rho} \tag{2}$$

Where σ is the conductivity of the tissue (S/m)

The electric field E is calculated inside the human brain with and without tumor using SEMCAD X tools. The percentage change of the E-field is shown in Fig. 4. These calculations are performed when the antenna with etched slots and 5-mm water pad are used. The 3D representation of this figure is shown in Fig. 5. The same analysis is repeated for the triangular patch without slots. The percentage variation of the E-field is shown in Fig. 6. It is clear from this figure that, the percentage change of the E field is high and that there is concentrated field at the edge of the antenna.

The SAR values are calculated in the entire brain equivalent model. Two cases are also considered. The first case is the SAR values in the presence and absence of a tumor when the etched slots in the triangular patch shown in Fig. 1 are used . The second case considers the SAR values in the presence and absence of a tumor for triangular patch without slots. Water pad of 5 mm thickness placed just above the triangular patch is used in both cases. The percentage

changes of SAR values with and without slots are shown in Figs. 7 and 8, respectively. The figures show that the percentage change of SAR values is high in both cases. The effect of reducing the thickness of the water layer pad is shown in Fig. 9, by using 2-mm thickness layer. The percentage change of SAR is noticed to be reduced.
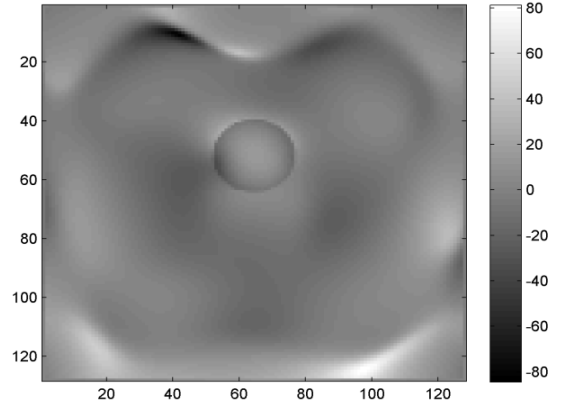

Figure 4. Percentage of E field change with the presence of tumor for antenna with slots and 5-mm water pad.
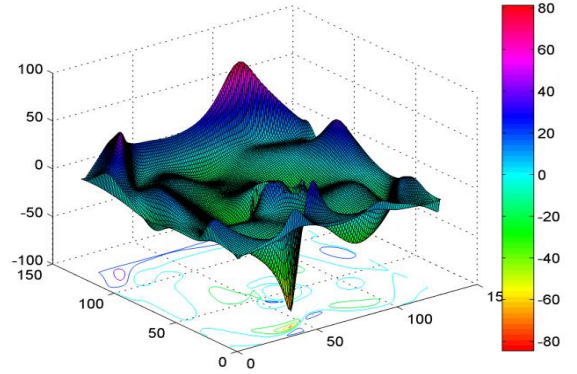

Figure 5. 3D representation of the percentage of E field variation with the presence of tumor for antenna with slots and 5-mm water pad.
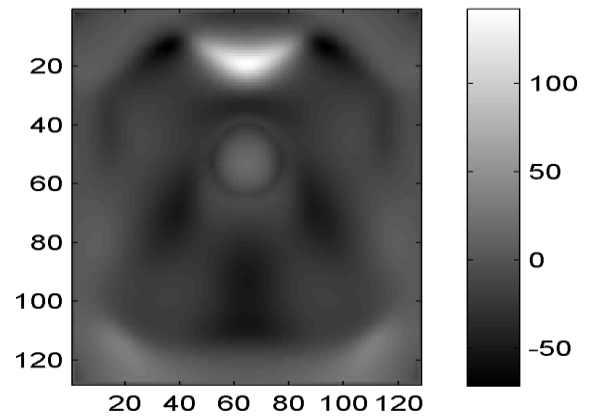

Figure 6. Percentage of E-field change with the presence of tumor for antenna without slots using 5-mm water pad.
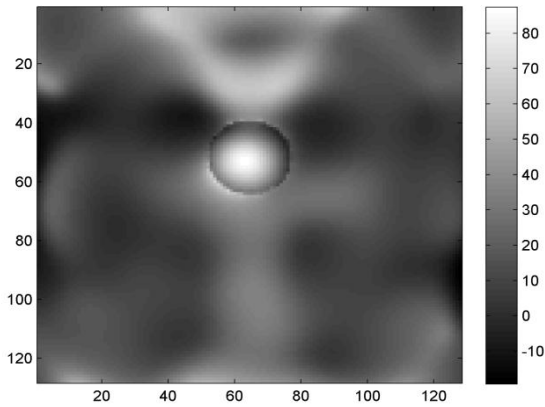
Figure 7.   Percentage of SAR change with 5-mm water pad, for antenna with slots.
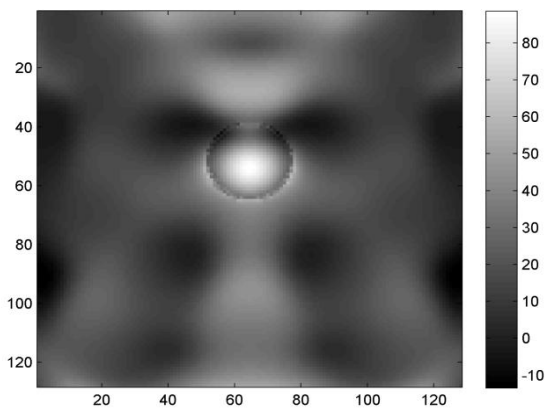

Figure 8.   Percentage of SAR change with 5-mm water pad, for antenna without slots.
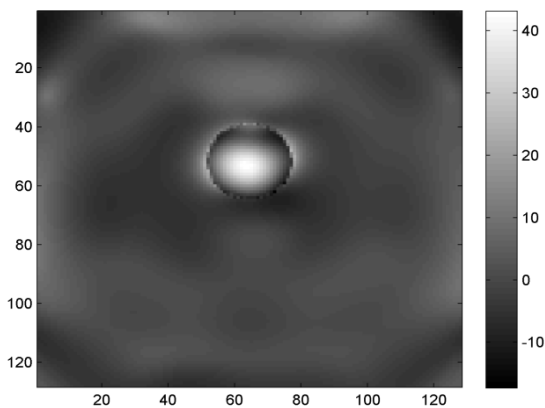

Figure 9.   Percentage of E field change with the presence of tumor for antenna with slots and 2-mm water pad.

IV.   CONCLUSIONS

A small size triangular PIFA structure for applications of microwave hyperthermia treatment and microwave imaging of the human head is proposed. The compactness has mainly been achieved by adding a fresh water pad just above the triangular patch. The optimum thickness size is found to be 5-mm. The percentage change of the E field as well as SAR values in the presence and absence of a tumor have been calculated using SEMCAD tools. Remarkable variations are observed. The proposed structure is thus promising for medical diagnoses and treatment of brain tumors.

REFERENCES

[1] X. Yang, J. Du, and Y. Liu, "Advances in Hyperthermia Technology," Proceedings of the 2005 IEEE Engineering in Medicine and Biology 27th Annual Conference, Shanghai, China, September, 2005.

[2] O. Işık, E. Korkmaz, and B. Türetken, "Antenna Arrangement Considerations for Microwave Hyperthermia Applications," General Assembly and Scientific Symposium, 2011.

[3] E. Neufeld, M. Pauildes, M. Capstick, G. v. Rhoon, N. Kuster, "Recent Advances in Hyperthermia Cancer Treatment," Asia-Pacific International Symposium on Electromagnetic Compatibility, Beijing, China, April 2010.

[4] H. Kusuma, A.-F. Sheta, I. Elshafiey, Z. Siddiqui, M. A. S. Alkanhal, S. Aldosari, S. A. Alshebeili, and S. F. Mahmoud, "A New Low SAR Antenna Structure for Wireless Handset Applications," Progress In Electromagnetics Research, Vol. 112, 23-40, 2011.

[5] IE3D Documentation, Mentor Graphics, http://www.mentor.com/electromagnetic-simulation/products/ie3d-si.

[6] SEMCAD X. Documentation, SPEAG, http://www.speag.com/products/semcad/overview/.

[7] Z. D. Liu, P. S. Hall, and D. Wake, "Dual-frequency planar inverted F antenna," *IEEE Trans. Antennas Propagat.,* vol. 45, pp. 1451–1458, Oct. 1997.

[8] C. R. Rowell and R. D. Murch, "A compact PIFA suitable for dual-frequency 900/1800-MHz operation," *IEEE Trans. Antennas Propagat.*, vol. 46, pp. 596–598, April 1998.

[9] G. H. K. Lui and R. D. Murch, "Compact dual-frequency PIFA designs using LC resonators," *IEEE Trans. Antennas Propagat.*, vol. 49, pp. 1016–1019, July 2001.

[10] F. R. Hsiao, H. T. Chen, G. Y. Lee, T. W. Chiou, and K. L. Wong, "A dual-band planar inverted-F patch antenna with a branch-line slit," *Microwave Opt. Technol. Lett.*, vol. 32, pp. 310–312, Feb., 2002.

[11] C. W. Chiu and F. L. Lin, "Compact dual-band PIFA with multi-resonators," Electron. Letters, vol. 38, no. 12, pp. 538-539, 2002.

[12] C. Li, M. Capstick, E. Neufeld, N. Chavannes, and N. Kuster, "Optimization of Patient Position in Hyperthermia Treatment for Head and Neck Region," International Symposium of Antennas and Propagation Society, 2009.