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Sergio Curto
Dublin Institute of Technology

T.S. P. See
Institute for Infocomm Research

Z. N. Chen
Institute for Infocomm Research

Patrick McEvoy
Dublin Institute of Technology

Max Ammann
Dublin Institute of Technology, max.ammann@dit.ie

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Interaction of RF-Hyperthermia Applicator with High Fidelity Human Body Model

S. Curto* (1), T. S. P. See (2), Z. N. Chen (2), P. McEvoy (1)
and M. J. Ammann (1)
[1]Antenna and High Frequency Research (AHFR) Group
Dublin Institute of Technology, Kevin St., Dublin 8, Ireland
[2]Department of Radio Systems, Institute for Infocomm Research
20 Science Park Road, Teletech Park, #02-21/25, Singapore 117674
E-mail: sergio.curto1@student.dit.ie

Introduction

The proliferation of hand-held wireless and cellular consumer products over the last two decades has prompted a beneficial increase in the research to minimize exposure to human tissue. Motivated by safety concerns, most of the reports focused on studies using communication frequencies. On the other hand, medical applications have exploited the ISM (Industrial Scientific and Medical) frequencies with the 434 MHz frequency band proposed for therapeutic applications such as hyperthermia [1], [2]. In this case, reduction of the radiating applicator dimension and efficient delivery of electromagnetic energy without skin burning are priority considerations.

The interaction between an RF-Hyperthermia applicator and a human body model is investigated and presented in this paper. A numerical High Fidelity (Hi-Fi) human body model developed by REMCOM is used in the XFDTD electromagnetic solver. The frequency-dependent dielectric constant and conductivity used in the Hi-Fi human body model are obtained from data of anatomical human bodies. When designing antennas for medical applications, from the electromagnetic point of view, the human body can be considered as an irregular, inhomogeneous and lossy dielectric object placed near the antenna [3]. A compact planar antenna printed on a PCB is designed to operate at the Industrial Scientific and Medical (ISM) frequency band of 434 MHz. The performance of the antenna is investigated when in close proximity to the human body model. This simulation setting represents actual setups in cancer therapy clinics. The impedance matching, SAR (Specific Absorption Rate) and radiated field distribution around the human body are examined.

Antenna Geometry and Human Body Model

The proposed compact patch antenna illustrated in Figure 1, is printed on a double-sided Taconic RF-35 dielectric substrate with 2.97 mm thickness and on a 130 mm x 130 mm area. The top of this antenna comprises a circular patch of radius R1 and a concentric annular ring of inner radius $R2$ and outer radius $R3$. In the ground plane, and concentrically positioned behind the circular patch, two rectangular slots, of width w, intersect an impedance matching circular slot, of radius $R4$. The rectangular slots are of unequal lengths $L1$ and $L2$. The optimized dimensions are: $R1 = 42$ mm, $R2 = 51$ mm, $R3 = 62$ mm, $R4 = 10$ mm, $L1 = 106$ mm, $L2 = 108$ mm, $w = 4$ mm. The 50 Ω feed is in the concentric annular ring at the rectangular coordinates (40, 40) mm, considering the centre of the circular patch as the coordinate system origin.

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The numerical Hi-Fi human body model is based on the data from the Visible Human Project, and comprises 23 dielectric and conductivity frequency-dependent materials [4], [5].

In the FDTD simulation, a mesh cell size respect to *x*-, *y*- and *z*- axes of 5 mm x 5 mm x 5 mm is used for the human body model. Around the antenna volume, and extended in *x*, *y* and *z* directions, an adaptive mesh of size 1 mm x 1 mm x 1 mm is used to increase the accuracy in the antenna structure and in its proximity. The simulation time step is 1.966 ps. The two constraints are $dh < \lambda_{min}/10$ and $dt < dh/(c\sqrt{3})$, where dh is the spatial step size, λ_{min} is the wavelength of the highest frequency under investigation, dt is the time step, and c is the speed of light. To achieve convergence in the simulation, the impedance performance is calculated for a Gaussian monocycle source of 32*dt* pulse width automatic convergence with a -30 dB convergence threshold and a maximum of 10E6 time steps is used. For the steady-state evaluation, a sinusoidal source centered at 434 MHz with the same automatic convergence as mentioned before is used.

The antenna is positioned at the back of the human body, centered respect the backbone and at a separation from the top of the head of 48 cm as shown in Figure 2. The evaluation is done for a range of antenna-body distances from touching the human body to 18 mm away.

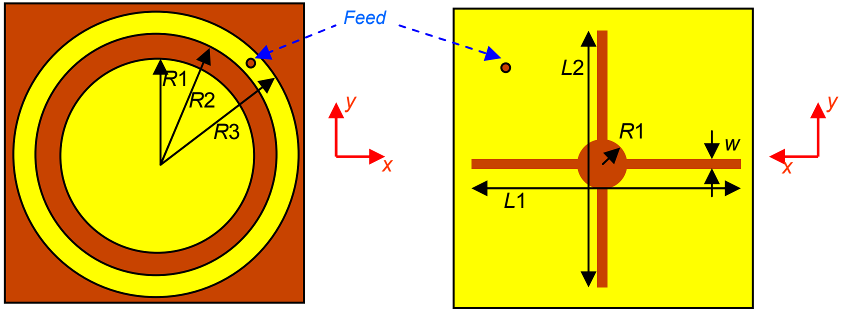

Fig. 1: Proposed Compact Patch Antenna, (a) Ring/Patch surface, (b) Groundplane/Slots surface.

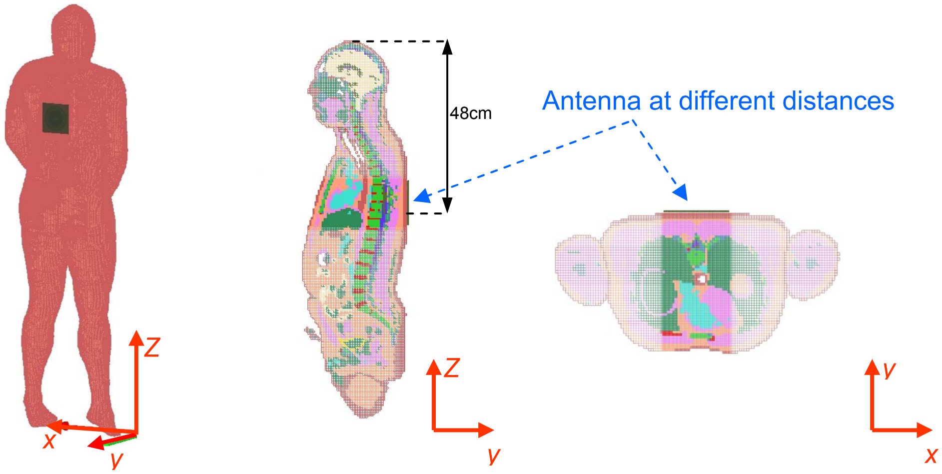

Fig. 2: Hi-Fi Human Body Model and antenna placement, (a) 3D model, (b) *yz*- plane, (c) *xy*- plane.

Results

The simulated and measured S11 of the antenna in free space is shown in Figure 3a. The results show good agreement at 434 MHz, the resonant frequency of interest. Figure 3b compares the simulated S11 of the antenna in free space and at the different distances of the body model. The comparison shows that the close presence of the body model affects the S11 and produces a detuning of the resonance frequency. This detuning is due to both the impedance mis-matching and power absorption by the body [6]. It is shown that the detuning is critical when the antenna is in direct contact with the human tissue. For the 2- and 4- mm cases the detuning is significant and then it decreases as the antenna tissue distance increases.

Figure 4 shows the peak SAR averaged over 1 g of layered tissue volume for different antenna tissue distances. It is clearly shown the exponential distribution of peak SAR for the different distances.

Figure 5 shows the distribution of the radiated E-field around the human body in the *xy*-plane when the antenna is 2 mm distant from the human body and at different time stages, namely, the 301st, 101st, and 3001st time steps. It can be seen that the radiation of the fields from the antenna is greatly blocked by the human body so the attenuation in the direction opposite to the body is more than 70 dB. It can be seen how the radiation changes and the penetration depth increases as the time steps increase.

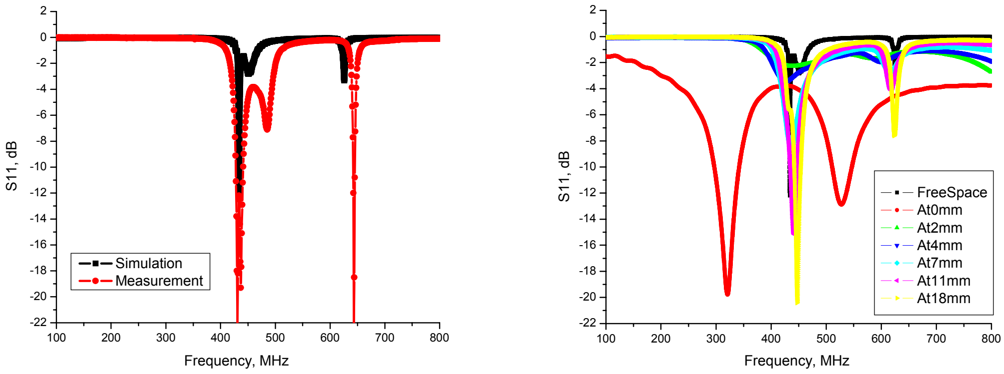

Fig. 3: S11 comparison, (a) Simulated and measured S11 in free space, (b) S11 at different distances from the body model.

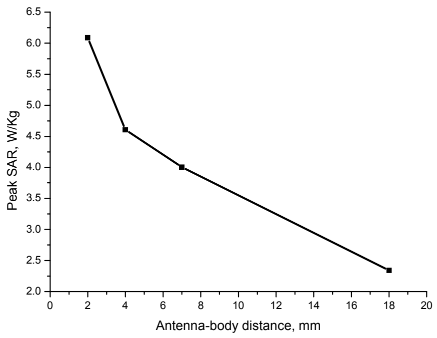

Fig. 4: Peak SAR in the body for different antenna-body distances.

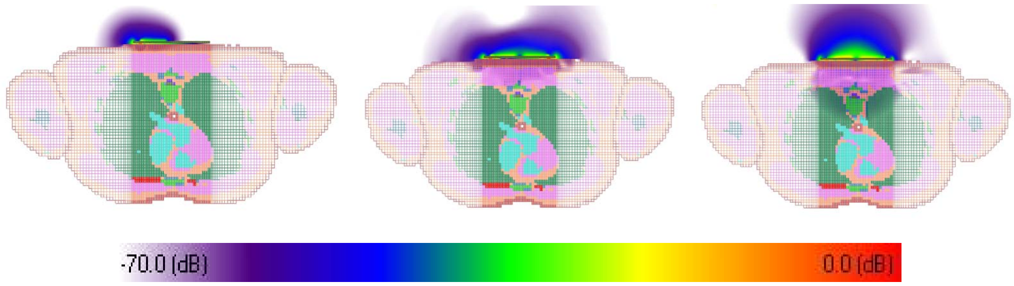

Fig. 5: E-Field distribution (a) 301st time step, (b) 1001st time step, (c) 3001st time step.

Conclusion

A compact patch antenna working at the 434 MHz ISM frequency band is proposed as an RF-Hyperthermia applicator. The electromagnetic interaction in terms of S11, SAR and E-Field distribution of the antenna with a High Fidelity human body model is investigated. This analysis provides useful information for engineers and clinical staff to develop more efficient and smaller antennas for medical applications, in particular for RF-Hyperthermia cancer therapy, where the size of the antenna determines tumor accessibility.

Acknowledgments

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