Comparison Study of Layered Homogeneous Models with Detailed Human Tissue Models for Through-body Communications

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Abstract— Any wireless communication between implantable antenna and an external off-body antenna suffers significant link loss due to the lossy nature of living human tissues. This link degradation is normally unpredictable and varies for different parts of the human body. To study an implantable communication scenario, complete setup is generally simulated using a full wave electromagnetic simulator. Such simulation requires human body phantoms having electrical properties such as permittivity and bulk conductivity, or even mass density similar to that of real body tissues. It has been observed that geometry of such phantoms is usually chosen as simple as possible to decrease the required computational resources and the overall time for the completion of the simulation. It is difficult to predict how much error is expected when realistic phantom is replaced by such geometrically simpler phantom. This study focuses on a comparison of the usefulness of using realistic human body phantoms over geometrically simple body phantoms for through-body communication simulation. To study this comparison, an implantable antenna, placed inside a human stomach model, is set to communicate with an off-body antenna at Medical Implant Communication Service (MICS) band. Keeping the distance between implantable antenna and off-body antenna constant, the realistic human body phantom is then replaced by two types of layered body phantoms with different complexity. Results in the form of calculated s-parameters and phantom complexity metrics are further investigated to conclude the study.

1. INTRODUCTION

Implantable devices for biomedical applications play vital role in building comprehensive telemedicine wireless communication networks. Before an implantable device is proposed, it is usually thoroughly simulated at system level, using numerical methods in order to study the electromagnetic propagation loss when the DUT is placed inside human body. Computerized MRI scanner deduced, detailed body phantoms are finding increasingly important role in the attempt to test the performance of such implantable devices on system level. A number of 3D phantoms, deduced from MRI scans of living subjects [1, 2], depicting indirectly measured electrical properties of human tissues, are widely used, for case to case based, implantable device, design problems. These models generally have frequency-dependent electrical properties, and they are similar in shape to realistic human body parts and thus geometrically complex. Example of such complex phantoms for medical imaging and implantable applications are presented in [4]. Alternatively another simpler approach is widely used, where dense material blocks or homogeneous layers with constant electrical properties similar to those of predominant human tissues are built and used in EM simulations for implantable devices problems [6, 7]. These mainly homogeneous blocks, consist of simple geometric shapes which result in low mesh complexity, during modeling in 3D CAD tools, and are therefore far less resources hungry when simulated using full wave EM solvers. The main problem limiting the use of layered homogeneous models, is related to their accuracy and consequently their reliability. This study aims to assess the reliability of such simpler models in comparison with the more complex structures of realistic body-mimicking models. Towards this end, a theoretical scenario is discussed through extensive simulations, in which the communication between an implantable device, located inside a human stomach model, and an off-body device placed near the abdomen is investigated. A novel, compact, multilayered, implantable antenna, operating at 403 MHz, is used to establish a through-body communication scenario with a near-body transceivers antenna. Keeping in mind the detuning effect of implantable and near-body antennas, both antennas are matched properly with respect to the surrounding human tissue models. Three different phantom models are compared in Section 2 and the simulated results are further investigated.

2. SIMULATION SETUP

The proposed implantable setup in order to investigate through body communication consists of an implantable antenna shown in Figure 1, placed inside the stomach of a realistic body phantom. The used antenna consists of three substrate layers of Rogers RO3210 ($h = 0.635$ mm, $\epsilon_r = 9.4$ and

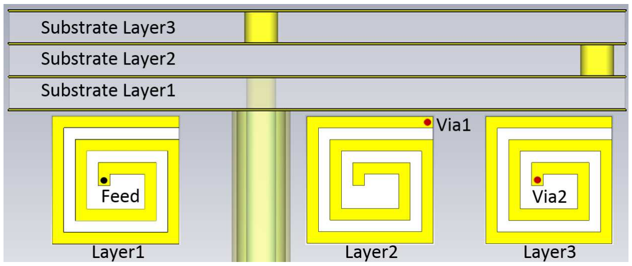

Figure 1: Geometry of implantable antenna operating at MICS band.

Tissue	ϵ_r	σ (S/m)
1- Stomach	67.51	1.00
2- Abdominal Muscle	57.15	0.79
3- Body Average	35.00	0.60
4- Gallbladder	61.25	1.13
5- Large Intestine	62.63	0.95
6- Liver	51.27	0.65
7- Pancreas	61.56	0.87
8- Small Intestine	66.19	1.90
9- Spleen	63.27	1.02

Table 1: Electrical properties of human organs at MICS band.

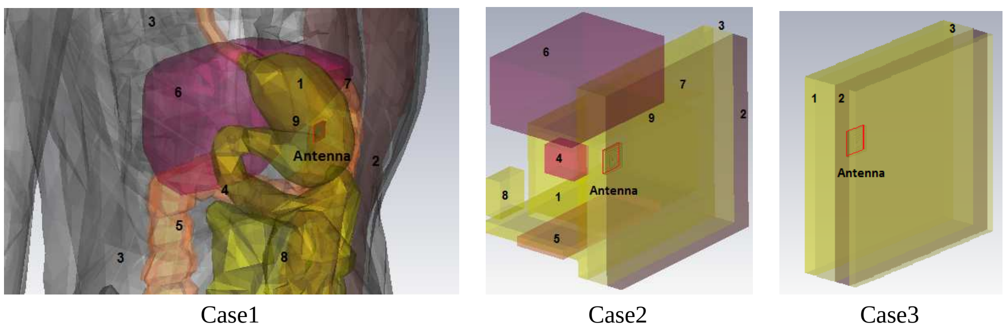

Figure 2: Implanting antenna in realistic human phantom (Case1), complex layered phantom (Case2) and simple layered phantom (Case3).

$\tan\delta = 0.006$) coated with copper having spiral and meandered configuration. Three spiral layers having 1 mm thick copper strip, connected to each other through via1 and via2, realize a radiating resonance at 403 MHz, MICS band. These layers are stacked to form a 3D meandered patch, in an attempt to achieve the desired compactness for an implantable antenna. The antenna used in this study is designed and matched in accordance to its operation inside stomach of a realistic human body phantom. On the other hand, a wideband antenna having directional radiation pattern with realizable gain ranging from 4 dB to 4.5 dB at MICS band is placed near the abdominal region of the phantom, to operate as an off-body transceiver antenna. Keeping the location and operation of implantable and off-body antennas constant, three types of phantoms, representing human tissues have been studied as described in Figure 2. The properties of human tissues considered in this study are listed in Table 1 and were presented in [8, 9]. Note that the average human tissue properties at MICS band [9] ($\epsilon_r = 35$, $\sigma = 0.60$ S/m) have been assigned to all other organs of the body phantom that are not listed in Table 1. As shown in Figure 2, Case1 represents a realistic human phantom model that can be considered as a reference phantom. Case2 represents a geometrically simpler phantom model where dense material blocks are placed at the same location where real human tissues are located. This layered phantom represents a comparatively simpler model than that of the realistic body phantom presented in Case1. The simplest phantom model is presented in Case3 in which only those tissues which are in the LOS path of the implantable to off-body antenna communication link, are modeled for the simulation setup. These tissues are represented by dense homogeneous material layers with the implantable antenna placed inside the equivalent stomach layer.

3. RESULTS AND DISCUSSION

To study the performance of each phantom, Finite Difference Time-Domain (FDTD) solver with Finite Integration Perfect Boundary Approximation (FPBA) hexahedral mesh was used. Considering only the organs listed in Table 1, full wave simulation was performed for all three cases. The number of pulses to define steady state convergence criteria was 20, and it was carefully selected to ensure accuracy up to 1%. Simulation parameters including adaptive mesh refinement were kept constant for all three cases. It was observed that a total number of FDTD mesh cells was 6.573952×10^6

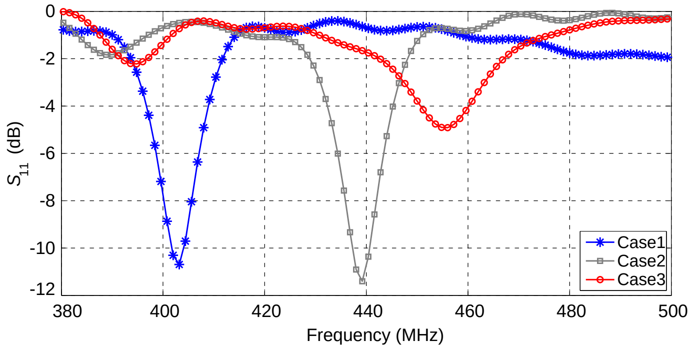

Figure 3: Return loss comparison of implantable antenna for all three cases.

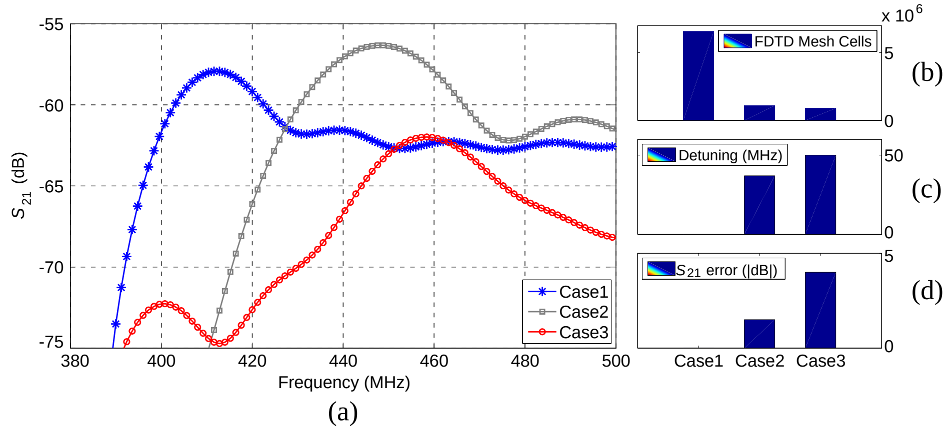

Figure 4: (a) S_{21} comparison for implantable antenna, (b) comparison of FDTD mesh cell count, (c) comparison of detuning in MHz, and (d) comparison of error observed in S-parameter for all three cases.

for Case1 as compared to that of 1.095438×10^6 and 0.898688×10^6 mesh cells generated in Case2 and Case3 respectively. In Case1, the antenna is placed inside stomach where it is surrounded by not only stomach tissue but also by other high water content and high conductivity tissues (like gallbladder, small intestine etc.). Intentionally the antenna is matched for this implant as evident by the simulated return loss shown in Figure 3. In Case2, realistic body organs are replaced by dense material blocks representing comparatively simpler models of human organs. Mesh cell count to simulate Case2 setup decreases but with the cost of significant detuning of resonant frequency from 403 MHz to 440 MHz. This shift is much greater than the total bandwidth assigned to MICS band, i.e., 3 MHz (402 MHz–405 MHz [9]) resulting in operation of the implantable antenna outside the designated, licensed, MICS band. Moreover, when this phantom is further replaced by the second even simpler layered phantom, widely used to test the performance of implantable antennas [6, 9], the resonance frequency further shifted towards higher frequencies. S_{11} for Case3 shown in Figure 3 depicts a detuning of 50 MHz, and a significant impedance mismatch. Simulation results indicate that not only the electrical properties, but also the location and even the very geometry of high conductive tissues play a significant role in through-body communication. Disregarding these tissues will introduce significant error in s-parameter calculation for any similar implantable simulation setup.

4. CONCLUSION

In this paper a realistic body phantom (Case1), a complex body phantom (Case2) and a widely used simple layered phantom (Case3) are compared in a through-body communication scenario at the MICS band. Complexity of these phantoms in terms of full wave simulator meshing density and resulting s-parameters accuracy were discussed. It was observed that when a realistic phantom was replaced by widely used simpler phantom models, significant detuning of the resonant frequency of the implantable antenna occurred. Due to the narrow bandwidth of MICS band, this detuning can be considered as unacceptable for such simulation setups. Further simulation results indicated that the additional computational requirements (computational resources and time) to simulate a realistic body phantom model is only 6 to 7 times the computational requirements, needed to simulate simple layered phantoms. Based on this observation, it is recommended to use realistic body phantom rather than layered phantoms for simulation setups created for implantable antennas, operating in the MICS band.

REFERENCES

1. Seo, J. K. and E. J. Woo, "Electrical tissue property imaging at low frequency using MREIT," *IEEE Transactions on Biomedical Engineering*, Vol. 61, No. 5, 1390–1399, 2014.
2. Motovilova, E., J. Su, and S. Y. Huang, "MRI-based electrical property mapping for human body," *IEEE International Conference on Computational Electromagnetics (ICCEM)*, 73–75, IEEE, 2015.
3. Segars, W. P. and B. M. W. Tsui, "MCAT to XCAT: The evolution of 4-D computerized phantoms for imaging research," *Proceedings of the IEEE*, Vol. 97, No. 12, 1954–1968, 2009.
4. Veressand Segars, A. I., W. Paul, J. A. Weiss, B. M. W. Tsui, and G. T. Gullberg, "Normal and pathological NCAT image and phantom data based on physiologically realistic left ventricle finite-element models," *IEEE Transactions on Medical Imaging*, Vol. 25, No. 12, 1604–1616, 2006.
5. Xu, L., M. Q.-H. Meng, and Y. Chan, "Effects of dielectric parameters of human body on radiation characteristics of ingestible wireless device at operating frequency of 430 MHz," *IEEE Transactions on Biomedical Engineering*, Vol. 56, No. 8, 2083–2094, 2009.
6. Huang, S., M. Tofighi, and A. Rosen, "Considerations for the design and placement of implantable annular slot antennas for intracranial pressure monitoring devices," *IEEE Antennas and Wireless Propagation Letters*, Vol. 99, 2014.
7. Nawaz, H. and M. Ali Babar Abbasi, "On-body textile antenna design and development for body-centric wireless communication systems," *12th International Bhurban Conference on Applied Sciences and Technology (IBCAST)*, 650–653, 2015.
8. Sani, A., A. Alomainy, and Y. Hao, "Numerical characterization of the radiation from implanted wireless sources considering different digital body phantoms," *3rd European Conference on Antennas and Propagation, (EuCAP)*, 459–461, 2009.
9. Kiourti, A. and K. S. Nikita, "A review of implantable patch antennas for biomedical telemetry: Challenges and solutions [wireless corner]," *IEEE Antennas and Propagation Magazine*, Vol. 54, No. 3, 210–228, 2012.