SUPPLEMENTARY ANALYSIS OF RF EXPOSURE SIMULATIONS OF LOW-POWER TRANSMITTERS

M. Prishvin, L. Bibilashvili, V. Tabatadze, R. Zaridze
Laboratory of Applied Electrodynamics, Tbilisi State University, Tbilisi, 0128, Georgia
Email: rzaridze@laetsu.org

Abstract

The objective of this paper is the analysis of the realistic exposure scenarios simulations stability. The paper contains analysis of the results obtained in terms of MMF/GSMA WP8 project [1]. Numerical simulations were performed on a human model [2] without consideration of detailed blood perfusion [3]. The blood perfusion, positioning of the antenna and the hand presence effects are described in this paper based on conducted research.

1. INTRODUCTION

After conducting a big amount of calculations with dipole, monopole, patch, PIFA and IFA antennas [1] it appeared that the results contain more valuable information than just peak values of temperature rise, averaged SAR, correlation etc. Simulations were conducted at different frequencies used in practice 300, 450, 900, 1450, 2450, 3700 and 6000MHz. In order to simulate possible mobile phone user's experience several separation distances between the head and the mobile handset models were considered: 5, 10 and 20mm. The aim of this paper is to conduct stability analysis of obtained results. The focus in the project was made on the peak values of 10g avg. SAR [7-10] and temperature rise. The simulations were conducted using the proprietary program package, which has been developed in the Laboratory of Applied Electrodynamics and Radio Physics – FDTDLab [4-6] in cooperation with Motorola Inc. (2002-2008). The validation of FDTDLab has been provided for EM and thermal solvers using different ways [5, 6].

According to the project specification the human head model [2] without a hand has been used for the calculations. It was decided to check how the presence of a hand affects the temperature rise and SAR distributions. It appeared that with the hand, taken into account, the results changed. Due to the high conductivity of the tissues the hand absorbs the energy and drastically changes the radiation pattern.

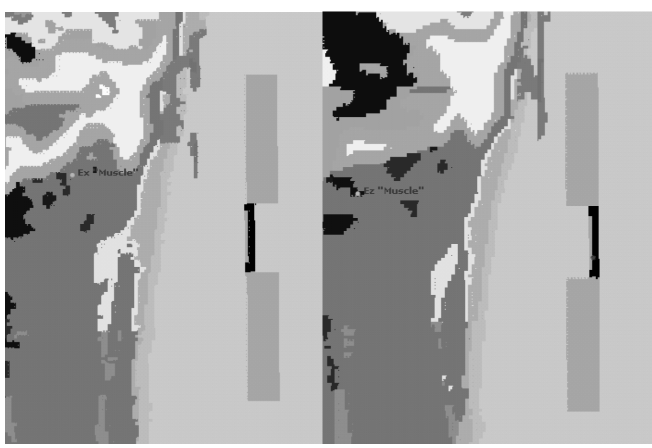
Another factor, which has not been discussed in the project description, is the placement of the antenna. It has been observed that the movement of the antenna drastically affects the results. All examined scenarios represent an ideal case: an infinite exposure with the antenna at a constant position. During the calculations it has been seen that when the antenna was shifted even by a small margin, the temperature rise and SAR values also significantly changed. The aspects of numerical simulation of RF exposure are investigated in detail in scope of this paper, namely the stability analysis of modeling results due to antenna placement, the possibility of resonance phenomena in the system, the effects of a hand and the directional blood perfusion on the temperature rise.

2. STABILITY ANALYSIS OF RESULTS AT HIGH FREQUENCIES

Data obtained for an inverted-F antenna (IFA) at 6000 MHz is presented in table 1. Two orientations of the antenna namely the "conventional" and "flipped" (see Fig. 1) were used for calculations.

Table 1. Data for IFA antenna operating at 6000 MHz, all data normalized to 1W input power.

6000 MHz	10 mm			20 mm		
	1g SAR	10g SAR	ΔT	1g SAR	10g SAR	ΔT
Conventional	24.8	4.77	3.01	11.21	2.56	1.45
Flipped	53.1	12.66	6.37	63.88	16.97	**7.78**



a) b)

Fig.1 a) flipped orientation of the antenna, b) conventional orientation of the antenna

At 20mm distance the IFA antenna in “flipped” orientation induced higher temperature rise compared to the same antenna at 10mm. Such behavior was unexpected since for all other calculations in terms of the project it had been observed that with the increase of the distance the peak values of temperature rise and averaged SAR decreased. This case has been investigated and several possible explanations of obtained results were found.

The first, previously not considered factor, is the radiation pattern and antenna placement. The far field pattern and near field distribution for the antenna in free space are shown on Fig. 2 and Fig. 3 respectively.

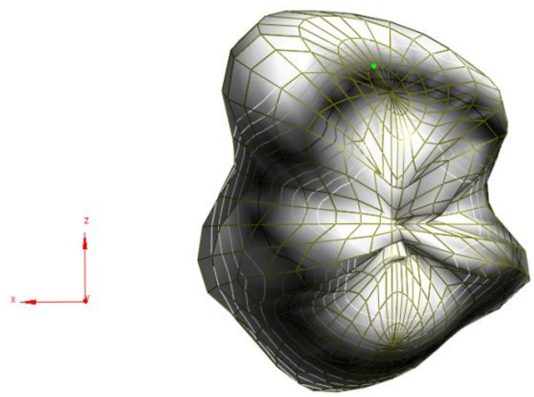


Fig. 2 Far field patter for the antenna

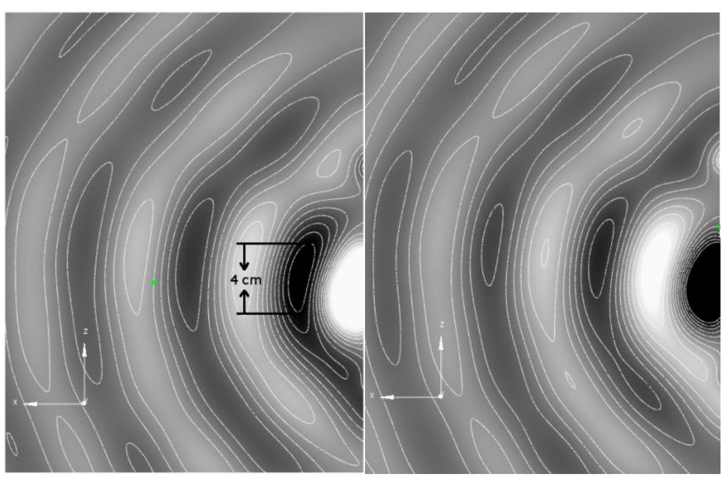


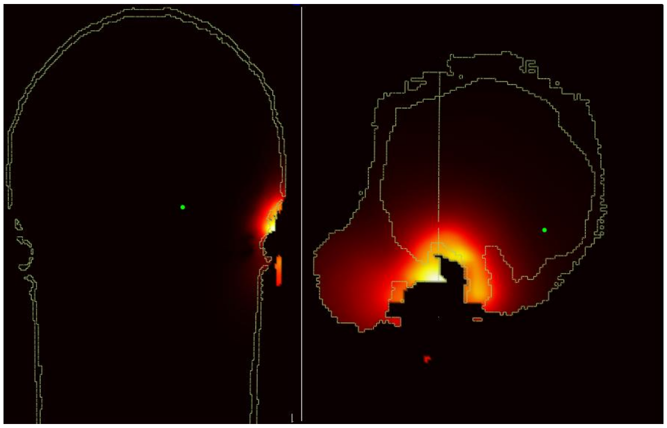
Fig. 3. Near Field distribution of the antenna. Antenna is not shown on the image.

The near field distribution is inhomogeneous; it propagates better in some directions, while in others it does considerably worse. From Fig. 3 it can be seen that at 6000 MHz field is concentrated in a small volume. At Fig. 3 the corresponding surface is approx 1x4cm. When the location of an object matches that area, the field values and the induced temperature rise are higher compared to the opposite case. The energy is concentrated in a small volume (Fig. 3). If in such case the antenna is shifted vertically by as small margin as 1cm, the field values in the model are drastically changed. At the same time the location of peak temperature rise and SAR values changed too. The heat flow through the boundary was different for scenarios, where the peak values of point SAR were located in different points of the model. In one case the peak value of 1g, 10g and or point SAR may be located in the earlobe; while in another it may appear on the surface of the head behind the ear Fig. 4 and Fig. 5.

a) b)

Fig. 4 Temperature rise for shifted position. Peak temperature rise is located in the earlobe.

a) XOZ slice b) YOZ slice.



a) b)

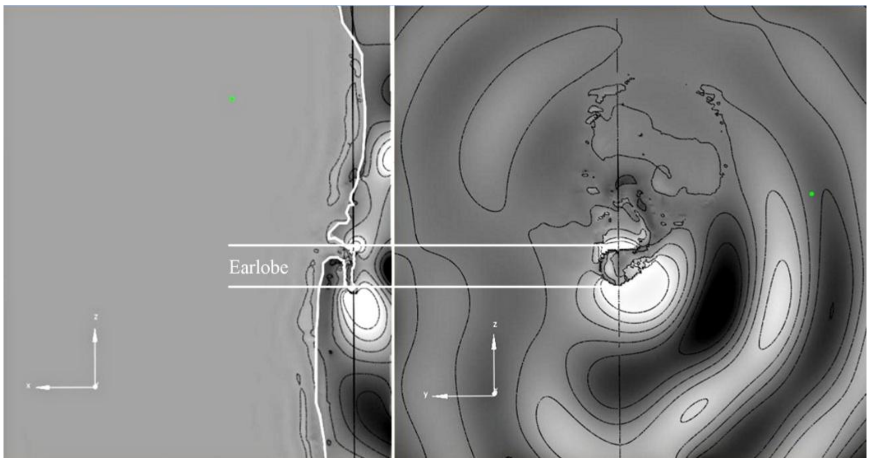
Fig. 5 Temperature rise for original position. . Peak temperature rise is located on the head surface.

a) XOZ slice b) YOZ slice.

In such cases, even if the peak values of SAR matched a difference in peak temperature rise values had been observed. The maximal observed difference was above 90%. The increases of SAR and temperature values, although less expressed, were observed at 3700 MHz.

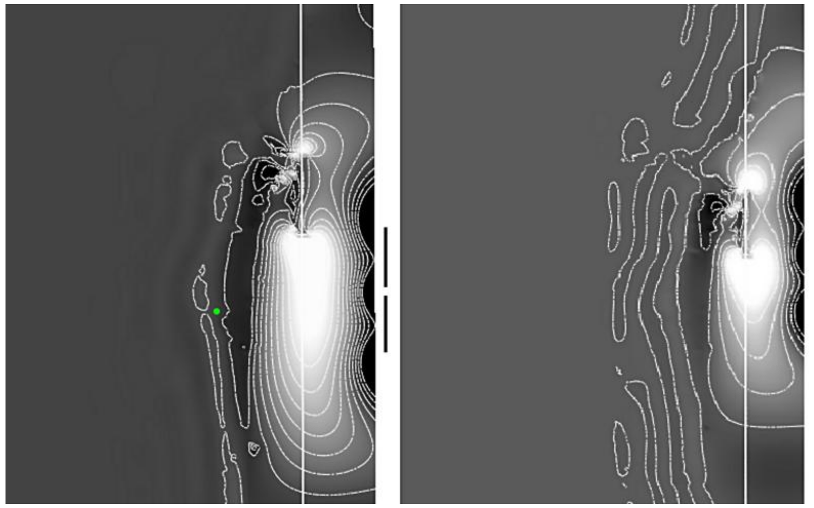
The second factor is the possible resonance that takes place in the “head-ear-antenna” system. It has been noticed that at high frequencies (from 3700 MHz and up), the distances between several parts of the model and the antenna may be comparable to the wave length, which for 6000MHz is 5cm. The dimensions of the ear or other parts of the model may be resonant at a given frequency. One of the consequences of having a resonance in the system appeared to be longer than usual calculation time. Described situation has been observed for the IFA antenna at 20mm. The resonance resulted in an unexpectedly high temperature rise.

From Fig. 6 it can be seen that the field concentration near the earlobe is very high. This is explained by the high conductivity values of corresponding materials.



a) b)

Fig. 6 near field distribution around the model. a) XOZ slice b) YOZ slice.



a) b)

Fig. 7. a) Field pattern for a L/2 dipole at 6000Mhz B) same dipole shifted by 10mm up.

The possibility of a resonance, the directed radiation pattern, result in the instability of the results according to antenna placement. The described situation was observed not only to the antennas with complex geometry, the same results have been obtained for dipoles Fig. 7. It can be seen how the field distribution changes if the dipole is shifted by 10mm along the Z axis. The resultant SAR and temperature rise distributions are different. Peak 10g SAR values are 3.61 W/kg and 6.01 W/kg respectively.

3. HAND EFFECT ON SAR IN THE MODEL

Due to the requirements of the project the anatomical model for all calculations consisted of the head apart from the rest of the body. Neither head nor shoulders were included. Antennas were placed next to the head model at different distances. There were fed by a sinusoidal signal at several frequencies until the process stabilized. It is obvious that an ideal scenario has been studied. In the real life a user holds the mobile handset in his hand, which changes the radiation pattern and redirects the energy along itself. With the hand present, the temperature rise values in the head are drastically reduced. The hand presence effect has been investigated using MAS [11-13] on a simplified model. The MAS method has been selected due to small computation time.

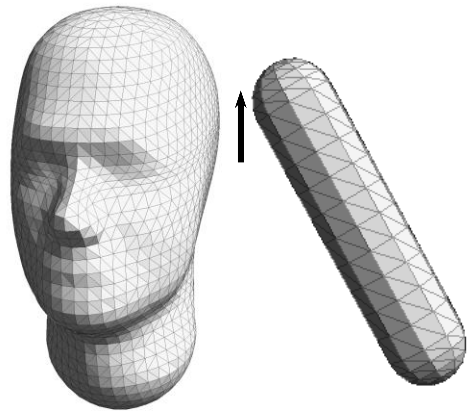


Fig. 8. The model of the head with a hand used for simulations.

At Fig. 8 the geometry used for calculations is presented. The arrow indicates the placement of the dipole. The head model is smoothed in order to use the MAS method for calculations. Both the head and the hand are filled with the muscle.

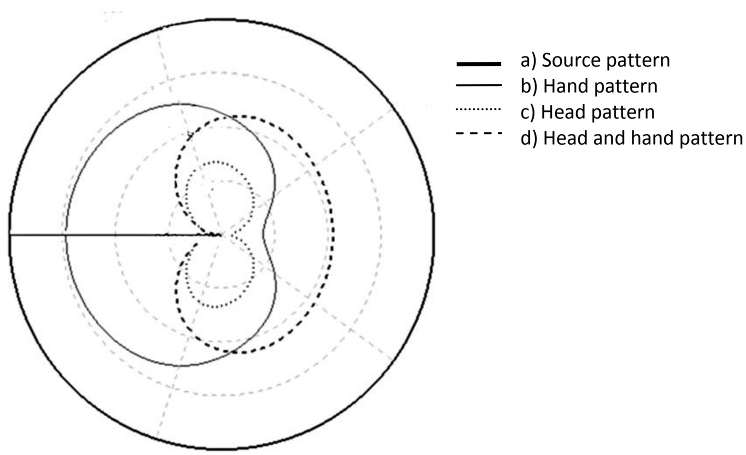


Fig. 9. Radiation pattern for several scenarios. It can be seen how the radiation pattern differs for each case.

From Fig. 9 it can be seen how the radiation patterns change for different exposure scenarios. The hand absorbs and redirects the energy Fig. 10. The peak SAR and temperature rise values in the head model are reduced.

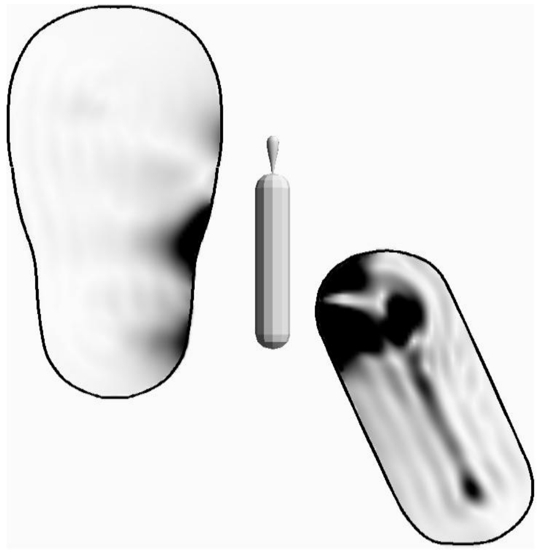


Fig. 10. SAR distribution in the head and hand model.

It has been shown how the radiation pattern changes with distance between the head and the antenna (see Fig. 11). At all distances except 4 cm the radiation patterns look alike. The 4cm distance may be resonant for the studied model. The conducted investigation shows, that in order to evaluate SAR and thermal effects in an anatomical model, the geometry of the head is not sufficient. The hand also should be taken into account.

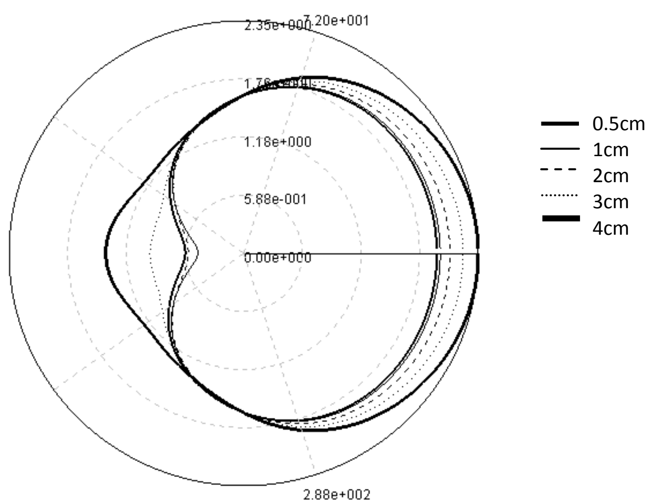


Fig. 11. Radiation pattern of the “head-hand” system for different dipole placement.

4. BLOOD PERFUSION

The software package FDTDLab was enhanced with several new features. A new model of blood perfusion with directional capillary blood flow [3] taken into account was added to it along with such features like analyzing peak values for temperature rise and SAR for selected tissues and regions. While the difference produced by two models was noticed, the thorough analysis is needed to quantify it. As an example the Fig. 1 shows the difference in temperature rise distribution computed for the same exposure condition using the conventional and new heat-exchange model. Both presented models are restricted to low power exposure conditions but may be extended to higher power levels by introducing reported in literature approximations of the basic thermal regulation mechanisms.

The modified model [3] is linear, and there is good correlation between peak 10g SAR values peek temperature rise values calculated according to it. At Fig. 12 results obtained using the modified model are presented. Fig. 12a shows temperature distribution according to conventional bio-heat equation, Fig. 12b distribution obtained according to the modified equation [3].The darker parts correspond to arterial endings while the lighter areas to venous endings, where the blood penetrates into examined volume.

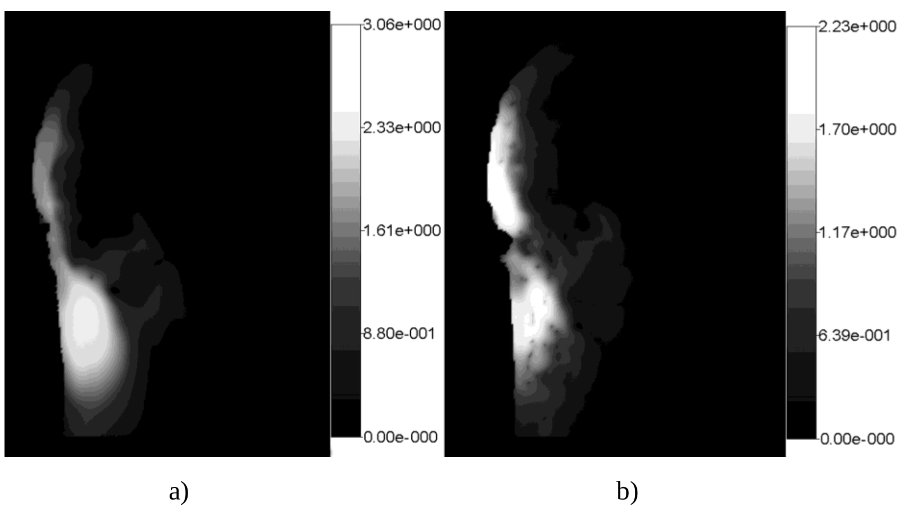


Fig. 12. Temperature rise for: a) Pennes model and b) modified model with new vascular structure model. SAR normalized to 1W input power.

The modified model is a subject of further study.

5. CONCLUSION

It has been shown that there is a large amount of factors to consider while simulating the RF exposure on a human model.

1. The minor variations of simulation parameters may drastically change the peak SAR and temperature rise values, especially at high frequencies.
2. The directional radiation pattern for planar antennas causes instability in respect to antenna position.
3. If the resonance takes place the peak values of SAR and temperature rise are significantly higher and simulation time is times bigger.
4. The resonance has been observed at 6000MHz. At other frequencies the main cause of the results instability is the directional radiation pattern.
5. The presence of a hand affects the radiation pattern and changes temperature distribution. With a hand taken into account the temperature rise in the head model is significantly lower.
6. Temperature rise, calculated according to the modified bio-heat equation [3] is slightly lower. Peak values of temperature rise are washed out.
7. For the mobile phone user it is useful to change the position of the handset during the communication process. Thus the peak values of SAR and temperature rise are reduced.

ACKNOWLEDGEMENT

This work was partially supported by the Mobile Manufacturers Forum (MMF), Brussels, Belgium & Hong Kong and the GSM Association (GSMA), London, UK.

REFERENCES

[1]. M. Prishvin, L. Bibilashvili, R. Zaridze. Developing a Thermal Exemptions Rationale for Low-Power Transmitters. Submitted to JAE.

[2]. N. Kuster. IT'IS Foundation. http://www.itis.ethz.ch/

[3]. Mikheil Prishvin, Liana Manukyan, Revaz Zaridze. "Vascular Structure Model for Improved Numerical Simulation of Heat Transfer in Human Tissue", 20-th International Zurich Symposium on Electromagnetic Compatibility, January 12-16 2009, Zurich, Switzerland. pp. 261-264.

[4]. Bijamov, A. Razmadze, L. Shoshiashvili, R. Zaridze, G. Bit-Babik, A. Faraone, "Software for the electro-thermal simulation of the human exposed to the mobile antenna radiation", Proceedings of VIII-th International Seminar/Workshop on Direct and Inverse Problems of Electromagnetic and Acoustic Wave Theory (DIPED-2003), Lviv, Ukraine, September 23-25, 2003, pp.173-176. http://www.ewh.ieee.org/soc/cpmt/ukraine/

[5]. R. Zaridze, N. Gritsenko, G. Kajaia, E. Nikolaeva, A. Razmadze, L. Shoshiashvili, A. Bijamov, G. Bit-Babik, A. Faraone, "Electro-Thermal Computational Suit for Investigation of RF Power Absorption and Associated Temperature Change in Human Body", 2005 IEEE AP-S International Symposium and USNC/URSI National Radio Science Meeting, July 3-8, 2005, Washington DC, USA. p. 175-178

[6]. L. Shoshiashvili, A. Razmadze, N. Jejelava, R. Zaridze, G. Bit-Babik, A. Faraone. “Validation of numerical bioheat FDTD model”. Proceedings of XI-th International Seminar/Workshop on Direct and Inverse Problems of Electromagnetic and Acoustic Wave Theory (DIPED-2006), October 11-13, 2006, Tbilisi, Georgia. pp. 201-204.

[7]. Md. R. Islam, Alex Razmadze, Revaz Zaridze, Giorgi Bit-Babik, and M. Ali, “Computed SAR and Temperature Rise in an Anatomical Head Model by Canonical Antennas”, BEMS Annual Meeting, BEMS-2009 Congress Centre, Davos, Switzerland, June 14 - 19, 2009, http://bioem2009.org/technical-program/.

[8]. R. Zaridze, A. Razmadze, L. Shoshiashvili, D. Kakulia, G. Bit-Babik, A. Faraone. Influence of SAR Averaging Schemes on the Correlation with Temperature Rise in the 30-800 MHz Range. EUROEM 2008 European Electromagnetics, 21-25 July 2008, Swiss Federal Institute of Technology (EPFL), Lausanne, Switzerland. pp.120

[9]. Bernardi et al. “Specific Absorption Rate and Temperature Increases in the Head of a Cellular-Phone User,” IEEE Trans. Microwave Theory Tech., vol.48, no.7, pp. 1118-1126, July 2000.

[10]. A. Razmadze, L. Shoshiashvili, D. Kakulia, R. Zaridze, "Influence on averaging masses on correlation between mass-averaged SAR and temperature rise". Journal of Applied Electromagnetism, vol.10, no 2. December 2008. pp. 8-21. http://jae.ece.ntua.gr/JAE December 2008/SAR and temperature rise Zaridze Paper 2.doc.pdf

[11]. R. Zaridze, G. Bit-Babik, K. Tavzarashvili, N. Uzunoglu, D. Economou, "*Wave Field Singularity Aspects Large-Size Scatterer and Inverse Problems.*" IEEE Transactions on AP, vol.50, No. 1, January 2002, p.50-58

[12]. D. Mazmanov, L. Manukyan, D. Kakulia, A. Razmadze, L. Shoshiashvili, R. Zaridze. MAS based software for the solving of diffraction and SAR problems on unbounded objects. Proceedings of XI-th International Seminar/Workshop on Direct and Inverse Problems of Electromagnetic and Acoustic Wave Theory (DIPED-2006), October 11-13, 2006, Tbilisi, Georgia. pp. 11-16

[13]. R. Zaridze, M. Prishvin, V. Tabatadze, D. Kakulia, "Hand Position Effect on SAR and Antenna Pattern in RF Exposure Study of a Human Head Model" BEMS-2009 Congress Centre, Davos, Technical Program, Switzerland, June 14 - 19, 2009, http://bioem2009.org/technical-program