Comparison of SAR in Human Body Radiated from Mobile Phone and Tablet Computer

Akihiro Tateno and Kensuke Tanaka
Graduate School of Engineering
Chiba University
Chiba, Japan
{a.tateno, ken-t.516}@chiba-u.jp

Tomoaki Nagaoka and Soichi Watanabe
National Institute of Information and Communications Technology
Tokyo, Japan
{nagaoka, wata}@nict.go.jp

Kazuyuki Saito, Masaharu Takahashi and Koichi Ito
Center for Frontier Medical Engineering
Chiba University
Chiba, Japan
{kazuyuki_saito, omei, ito.koichi}@faculty.chiba-u.jp

***Abstract*— Recently, wireless radio terminals such as mobile phones and tablet computers are increasing and developing rapidly. The effects of the electromagnetic (EM) waves in the human body from the wireless radio terminal have been paid attention. Therefore, we have calculated the specific absorption rate (SAR) in human tissues radiated from simple EM source models as like dipole antennas. In this paper, we constructed high-resolution numerical model of the flip phone and tablet computer. In addition, we compared the SARs in human body from the flip phone and the tablet computer using the finite-difference time-domain (FDTD) method. As the results, we found the SARs by the flip phone are higher than those by the tablet computer. All calculated SARs are below the safety guideline for RF energy exposure set up by the International Commission Non-Ionizing Radiation Protection (ICNIRP).**

Keywords—Specific absorption rate; Wireless radio terminal; Numerical model; Finite-difference time-domain method

I. INTRODUCTION

Recently, electromagnetic (EM) devices, which are usually used in vicinity of the human body, are developing and increasing rapidly. Therefore, the public concern about the influence of EM waves radiated from wireless radio terminals become more interesting. Absorbed EM energy mainly provides the thermal effect in tissues. The specific absorption rate (SAR) is used as a standard dosimetric parameter for EM wave exposure [1]. The SAR is defined using the following equation (1):

$$\mathrm{SAR}=\frac{\sigma}{\rho}E^2 \tag{1}$$

where σ is the conductivity of the tissue (S/m), ρ is the density of the tissue (kg/m^3), and E is the internal electric-field strength (V/m). Since measurements of SARs in the human body are so difficult because of the ethic issue, in this study, we evaluated the SARs using the computation with numerical models of the human.

Previously, we have calculated the SAR in the human body exposed EM waves radiated from the simple EM sources such as dipole antennas and planar inverted-F antennas with a metallic case [2]. However, there can be different influence to the human body between simple EM sources and actual wireless radio terminals. In addition, SAR evaluations in the human body from a tablet computer whose user is increasing in recent years as a new type of the wireless radio terminal have not enough. In this paper, we constructed the high-definition numerical model of the typical tablet computer and flip phone. Moreover, we compared calculated SARs from the flip phone to those from tablet computer using a female model.

II. DEVELOPMENT OF EM SOURCE MODELS

On the basis of shapes and lengths on actual parts such as a print circuit board (PCB), battery and antenna, components in the EM source models are constructed correctly using the computer aided design (CAD). In this study, although the EM source models include several antennas, we focused on the transmitting antenna for the 3rd generation (3G) communication system due to high radiation power. Therefore, operating frequencies are 900 MHz and 2 GHz bands.

In order to assess the validation of the EM source models, we calculated the reflection coefficient in a free space. Furthermore, we compared SAR distributions between measurements and calculations. In this study, we performed calculations by the XFdtd ver. 7.2.2.2 [3].

A. Flip phone model

Fig. 1 shows the high-definition closed flip phone model with $0.1 \times 0.1 \times 0.1$ mm^3 voxel grid. The size of the flip phone model is $49.0 \times 112.1 \times 16.6$ mm^3. The structure of the transmitting antenna for 3G is described in Fig. 1. As shown Fig. 1, the antenna for 3G is inverted-F antenna because of the shorting and feeding.

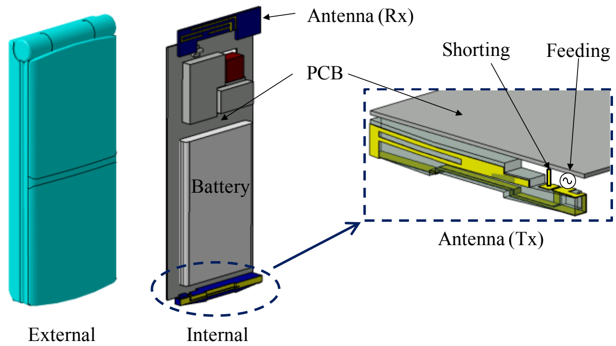

Fig. 1. Numerical model of the flip phone.

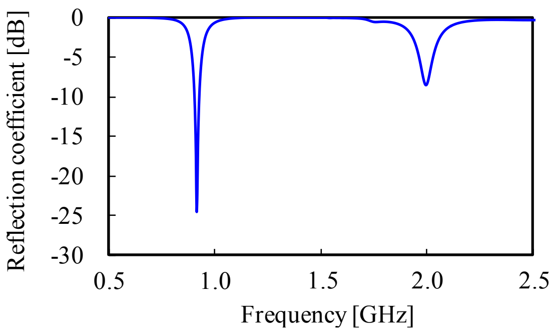

Fig. 2. Reflection coefficient at the transmitting atenna for 3G in a free space.

Fig. 2 shows the result of the reflection coefficient. We found the reflection coefficients at 900 MHz and 2 GHz are below -6 dB, respectively. Fig. 3 shows the measurement system for SAR distributions by the flip phone using the dosimetric assessment system (DASY). Fig. 4 shows the calculation model same for the condition of the measurement system. The physical properties of the liquid phantom are $\varepsilon_r = 41.0$, $\sigma = 0.9$ S/m, $\rho = 1{,}081$ kg/m^3 (at 900 MHz), $\varepsilon_r = 38.8$, $\sigma = 1.4$ S/m, 1,061 kg/m^3 (at 2 GHz), respectively. The physical properties of dielectric (a case of the liquid phantom) are $\varepsilon_r = 3.7$, $\sigma = 0.0$, $\rho = 1{,}000$ kg/m^3, respectively. The depth of the observation plane is 5 mm from the surface of the dielectric. Fig. 5 shows the result of measured and calculated SAR distributions. SAR distributions are normalized by each maximum SAR value respectively. In Fig. 5, we obtain the similar tendencies at both frequencies. For these results, we confirmed the validity of the flip phone for SAR evaluations.

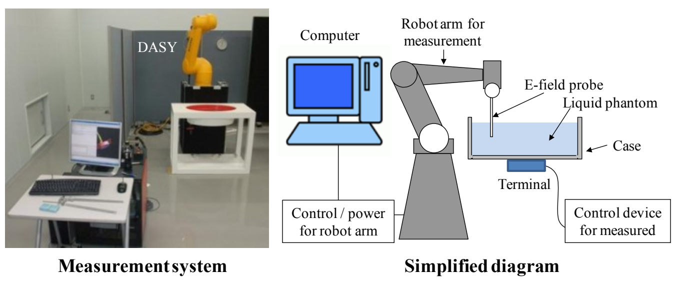

Fig. 3. Measurement system for SAR distributions by the flip phone.

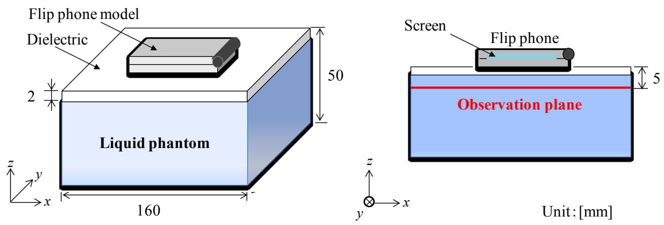

Fig. 4. Calculation model for SAR distributions by the flip phone model.

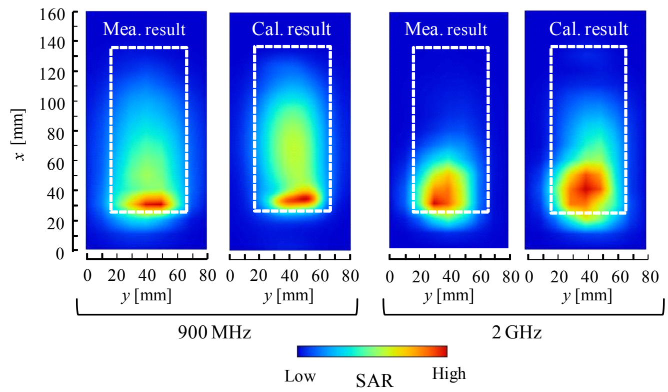

Fig. 5. Results of measured and calculated SAR distributions.

B. Tablet computer model

Fig. 6 shows the tablet computer model with 0.5 × 0.5 × 0.5 mm^3 voxel grid. The size of the tablet computer model is 186.0 × 241.5 × 8.0 mm^3. The structure of the antenna for 3G is illustrated in Fig. 7. The antenna for 3G in the tablet computer model is also inverted-F antenna and connected to the main PCB by the coaxial.

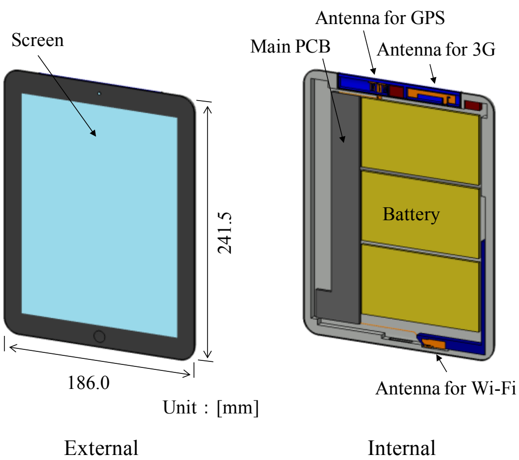

Fig. 6. Numerical model of the tablet computer.

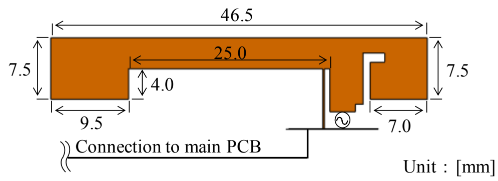

Fig. 7. Structure of the antenna for 3G.

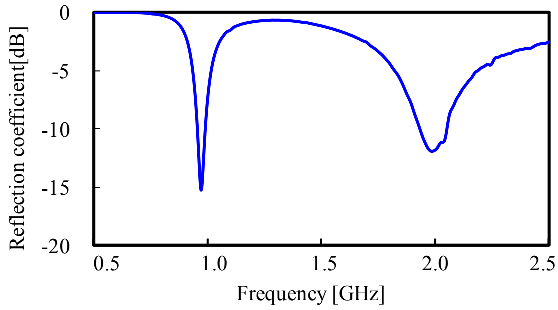

Fig. 8. Reflection coefficient at the antenna for 3G in a free space.

Fig. 8 shows the reflection coefficient in a free space. As shown Fig. 8, the antenna for 3G resonated at 900 MHz and 2 GHz bands. In this study, the reference [4], which was measured the SAR distributions by tablet computer we modeled using the electric-field probe, was employed as the measurement results. Fig. 9 shows the calculation model under the same conditions of the measurement system. The physical properties of the liquid phantom are $\varepsilon_r = 54.6$, $\sigma = 1.0$ S/m, $\rho = 1{,}000$ kg/m^3 (at 900 MHz), $\varepsilon_r = 51.9$, $\sigma = 1.5$ S/m, $\rho = 1{,}000$ kg/m^3 (at 2 GHz), respectively. The physical properties of dielectric (a case of the liquid phantom) are $\varepsilon_r = 4.5$, $\sigma = 0.0$ S/m, $\rho = 1{,}000$ kg/m^3, respectively. The depth of the observation plane is 5 mm from the surface of the dielectric. Fig. 10 shows the results of the measured and calculated SAR distributions. SAR distributions are also normalized by each maximum SAR value respectively. As shown Fig. 10, calculated results were in good agreement with measured results at both frequencies.

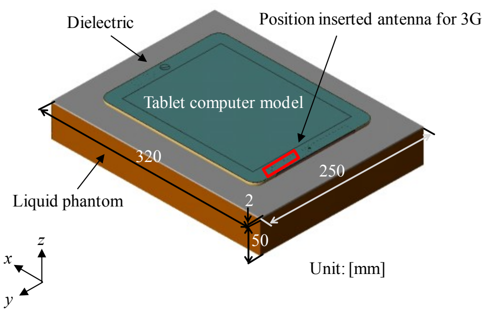

Fig. 9. Calculation model for SAR distributions.

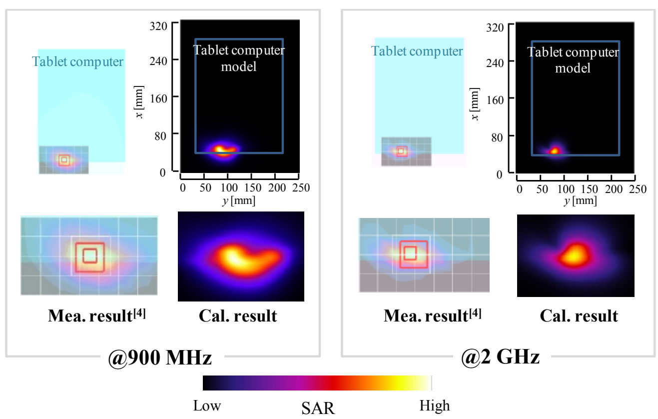

Fig. 10. Results of measured and calculated SAR distributions.

III. SAR Evaluations in Human Body

A. Calculation model

Fig. 11 shows the calculation model when the EM source models were placed close to the abdomen on the numerical model of Japanese female [5]. Electric properties and densities of tissues and organs are referenced in [6]. In this study, for the worst case evaluation, the input powers were 0.25 W at both frequencies in consideration of the maximum power in the 3rd mobile communication system. The height of feeding points each EM source model is 110 mm below the navel of the female model in view of the actual situation using a tablet computer, moreover in order to compare SARs between the tablet computer and the flip phone in the same condition. The tablet computer model placed horizontally. The median line of the female model corresponds to the bisector of the short side of the flip phone model and the tablet computer model. The distance between the surface of the female model and the EM source model was 10 mm. The cell size of the female model is 2.0 × 2.0 × 2.0 mm^3, therefore the non-uniformed cell was employed (flip phone: 0.1 – 2.0 mm, tablet computer: 0.5 – 2.0 mm). The entire calculation regions of the flip phone and tablet compute model were 768 × 768 × 1668 mm^3. We used perfect matched layer boundary condition (eight layers) for the boundaries of the both calculated regions. The calculations were performed by XFdtd ver.7.2.2.2 [3].

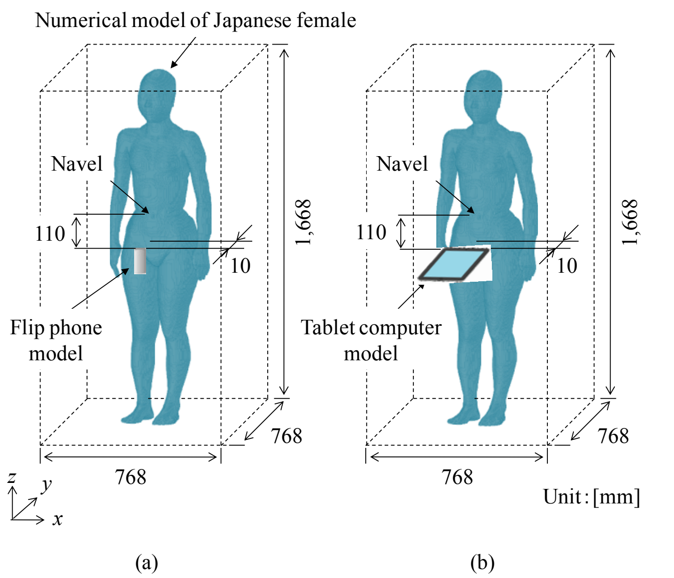

Fig. 11. Calculation model for when (a) flip phone model (b) tablet computer model was placed close to the abdomen on the numerical model of female.

B. Results

TABLE I shows the peak 10-g-averaged SAR in the female. In comparison with the frequencies, 10-g-averaged SARs at 2 GHz are higher than those at 900 MHz locally. Moreover, we also confirmed the 10-g-avrveraged SARs by the flip phone model are higher than those by the tablet computer model.

TABLE II shows the whole-body-averaged SAR. As shown in TABLE II, whole-body-averaged SARs at 900 MHz are higher than those at 2 GHz in contrast to the 10-g-averaged

SAR. This is because the wavelength at 900 MHz is longer than 2 GHz. Therefore, the EM wave at 900 MHz penetrates human body deeply. Compared to the EM sources, whole body SARs by flip phone model are also higher than those by the tablet computer model.

TABLE I. PEAK 10-G-AVERAGED SAR

EM source	**Peak 10-g-averaged SAR [W/kg]**	
	900 MHz	***2 GHz***
Flip phone model	0.75	1.22
Tablet computer model	0.42	0.98

TABLE II. WHOLE-BODY-AVERAGED SAR

EM source	**Whole-body-averaged SAR [$\times 10^{-3}$ W/kg]**	
	900 MHz	***2 GHz***
Flip phone model	3.87	3.26
Tablet computer model	2.19	1.99

IV. CONCLUSION

In this paper, firstly we developed the high-resolution flip phone and tablet computer models. We confirmed the validation of both EM source models in the reflection coefficient and comparison of the SAR distributions between measurements and calculations. Secondly, we estimated the 10-g-averaged SARs and the whole-body-averaged SARs in the human body due to the flip phone and the tablet computer models.

As the result, we found the 10-g-averaged SARs by a flip phone are higher than those by a tablet computer. In the case of localized EM exposure to human body, the SARs is locally higher at 2 GHz, on the other hand, the total amount of the EM exposure is higher at 900 MHz. Furthermore, we confirmed the all calculated SARs are below the ICNIRP safety guideline for EM exposures (10-g-averaged SAR should be less than 2 W/kg, whole-body-averaged SAR should be less than 0.08 W/kg) [7] sufficiently. In near future study, we will evaluate SARs in a pregnant female and her fetus exposed to EM waves radiated from the flip phone model and the tablet computer model. In addition, we will estimate temperature elevations in the human body.

ACKNOWLEDGMENT

Part of this work was supported by the Strategic International Cooperative Program (Joint Research Type), of the Japan Science and Technology Agency.

REFERENCES

[1] IEEE Standard for Safety Levels With Respect to Human Exposure to Radio Frequency Electromagnetic Fields, 3 kHz to 300 GHz, IEEE Standard C95. 1-2005, Oct. 2005.

[2] A. Tateno, K. Saito, T. Nagaoka, S. Watanabe, M. Takahashi and K. Ito, "Temperature elevation in human fetuses at 13 weeks, 18 weeks, and 26 weeks of gestation due to a wireless radio terminal," The Bioelectromagnetics Society 34th Annual Meeting, pp.284-286, June 2012.

[3] Remcom Inc. (http://www.remcom.com/).

[4] FCC OET List Exhibits Report, FCC ID: BCGA1396.

[5] T. Nagaoka, S. Watanabe, K. Sakurai, E. Kunieda, S. Watanabe, M. Taki and Y. Yamanaka, "Development of Realistic High-Resolution Whole-Body Voxel Models of Japanese Adult Male and Female of Average Height and Weight, and Application of Models to Radio-Frequency Electromagnetic-Field Dosimetry " Physics in Medicine and Biology, Vol.49, pp.1-15, 2004.

[6] T. Togashi, T. Nagaoka, S. Kikuchi, K. Saito, S. Watanabe, M. Takahashi and K. Ito, "FDTD calculations of specific absorption rate in fetus caused by electromagnetic waves from mobile radio terminal using pregnant woman model," IEEE Trans. Microw. Theory Tech., vol. 56, no. 2, pp. 554–559, Feb. 2008.

[7] ICNIRP, "Guidelines for limiting exposure to time-varying electric, magnetic, and electromagnetic fields (0 Hz to 300 GHz)", Health Phys., vol. 74, no. 4, pp. 494-522, Apr. 1998.