Compliance of Induced Quantities in Human Model for Wireless Power Transfer System at 10 MHz

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***Abstract*— In this study, first, compliance of specific absorption rate (SAR) and induced electric field for wireless power transfer system is reviewed. Then, the SAR/induced electric field in the human body are computationally evaluated separately due to (i) magnetic field generated from/by the system and (ii) contact current. A two-step approach based on quasi-static approximation is used for the dosimetry for (i) while a finite-difference time-domain method is used for (ii). Computational results are compared with the limit prescribed in the guidelines to obtain insight about an allowable transfer power.**

I. INTRODUCTION

There has been increasing concern about adverse health effect due to electromagnetic waves. In addition, wireless power transfer systems with magnetically coupled coils attract attention. Compliance with the safety standard is needed for radio waves used in such systems because the expected transfer power is much larger than that used in wireless communications. One of the frequency bands considered for wireless power transfer is in the range of several to a few dozen megahertz. Particularly, a frequency of 13.56 MHz would be promising for this application, because it has been assigned for industrial, scientific and medical use.

For frequencies above 10 MHz, the specific absorption rate (SAR) is used as a metric for human protection [1, 2]. For localized exposure, the peak value of SAR averaged over 10 g of tissue is used, while the whole-body average SAR is used for whole-body exposure. In [3], the compliance of wireless power transfer is discussed by calculating the amplitudes of the magnetic and electric fields between the coupled coils. The transferring power was 60 W for the transfer distance of 2 m. The calculated electric/magnetic field strengths did not satisfy the reference level in the international guidelines/standards [1, 2]. In such cases, the basic restriction, local and whole-body SARs (basic restrictions), should be evaluated for assessing the compliance with the guidelines. Induced electric field due to contact current may be of interest when metallic object is located close to the wireless power transfer systems.

Computational dosimetry on local SAR due to wireless power transmission at 8 MHz was conducted with the finite-difference time-domain (FDTD) method [4]. Although the FDTD method is a very powerful method for solving for the interaction between biological tissue and electromagnetic fields, a high-resolution analysis is time consuming especially at lower frequencies and for curved structures. In addition, a two-step approach based on a quasi-static approximation was applied in [5]. First, the finite-element method was used to compute the magnetic field generated by the magnetically coupled coils. Then, dosimetry was conducted with the impedance method by considering the current distribution as a source. However, the transfer efficiency of the system considered was at most 30% or not strongly-coupled. In addition, the validity of the approach was not discussed by comparing the results to a full-wave electromagnetic analysis. In [6], we proposed similar two-step approach based on method of moment (MoM) and scalar-potential finite-difference (SPFD) method. In particular, quasi-static approximation has been valid for the dosimetry in 10 MHz band.

Computational dosimetry due to contact current has been conducted only at power line frequencies [7]. Recently, we extended the target frequency up to 110 MHz [8]. For contact current exposure, no specific scenario has been recommended especially from the stand point of compliance with the guidelines.

In the present study, computational dosimetry for local SAR and contact current has been demonstrated. Then, compliance aspect with wireless power transfer system is discussed.

II. COMPUTATIONAL MODEL AND METHODS

A. Numeric Human Model

Figure 1 shows the numeric Japanese male models. The human model of adult male named TARO [9] is segmented into 51 anatomic regions including the skin, muscle, bone, brain, heart and so forth. The original resolution of the human model was 2 mm. The height, weight, and surface area of the model are, respectively, 1.73 m, 65 kg and 1.78 m^2.

The dielectric constants of the tissue at each frequency are determined based on the database of 4-Cole-Cole equation plot, which was derived in [10].

B. Computational Methods

The magnetic field generated by coupled coils is first obtained using the MoM without considering the human body. The *in-situ* electric field is then computed by the SPFD method [11] with the successive over-relaxation. Compared to full-wave analysis (e.g. the FDTD method), the magnetic field source needs to be solved only once for a single system configuration, and the modelling of surrounding air region is not needed. This quasi-static nature leads to a greatly reduced

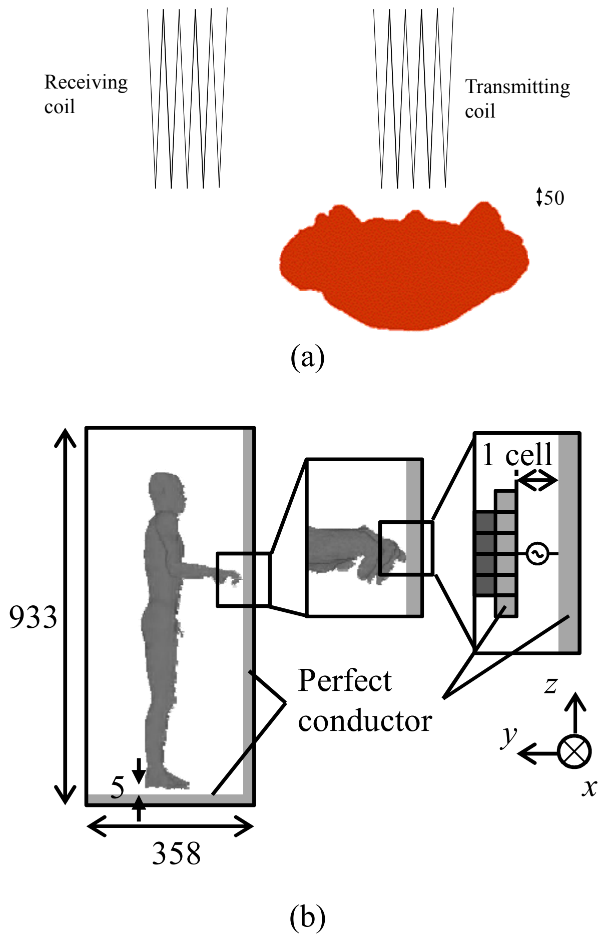

Fig. 1. (a) The geometry of the coils and the exposure conditions for human model (top view) and (b) ungrounded anatomical human body with voltage source for contact current.

computational effort especially when studying a variety of different human body models/ human-coil positions.

The FDTD method was used to investigate the induced current density/*in-situ* electric field in the human body because no detailed metallic structure exists in the exposure scenario.

C. Exposure scenario

Two scenarios are considered in this study. First scenario is the human dosimetry due to the magnetic field generated by magnetically coupled coils to estimate local SAR, as shown in Fig. 1 (a). The other is the contact current dosimetry as shown in Fig. 1 (b) which consider the ungrounded human body model which touch a metallic object. Note that the arm and fingers of TARO are bent manually to realistically simulate human contact with the metal. In addition, the second scenario does not consider a specific scenario because it may depend on exposure condition dramatically.

III. COMPUTATIONAL RESULTS

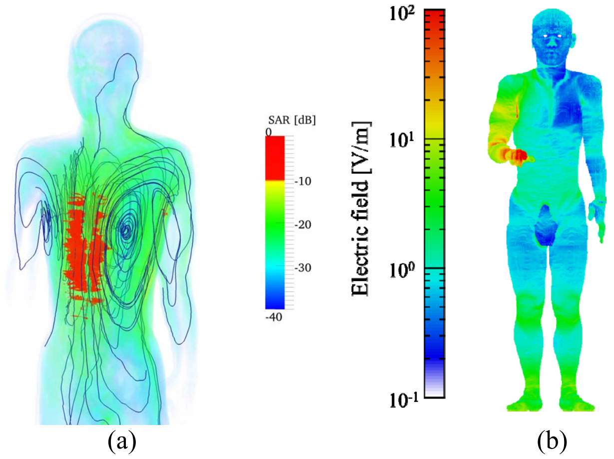

Fig. 2. (a) SAR distribution for the odd modes in TARO located in front of the transmitting coil, and (b) the induced electric field distributions for ungrounded human body at 10 MHz.

For different positions of human body relative to coils, the worst case exposure was shown that the human body was located directly in front of either of the coils, the height of the coil was in front of the chest, and the distance to the coil was as close as possible. For this worst case scenario, the highest SAR values are located in the muscle tissue in the chest at a depth of 10–20 mm. For satisfying the limit of local SAR of 2 W/kg, the maximal allowable transmitting power that satisfies the basic restriction limit was the order of 2,000 W. Note that mean amplitude of the magnetic field in the region where human occupies was 0.08 A/m for the transmitting power of 1 W. When considering the compliance with the reference level, the transfer power was 2 W.

For the scenario shown in Fig. 1 (b), the amplitude of the contact current to the human body is chosen as 20 mA, or the reference level recommended in the guidelines [2]. As shown in Fig. 2(b), the induced electric field becomes large only around the finger of the model. The maximum electric fields induced in the subcutaneous fat and the muscle were comparable to but still smaller than the basic restrictions specified in [2]. The maximum electric fields in the brain, spinal cord, and the heart are also well below the basic restrictions.

Summary

In the present study, computational dosimetry for local SAR and contact current for wireless power transfer system at 10 MHz was demonstrated. Then, the corresponding compliance aspect is discussed. For external field due to wireless power transfer system, allowable transfer power was 2,000 W, which was much larger than that estimated from the compliance with the reference level. For the exposure scenario for contact current was simplified in this paper because it is difficult to determine specific scenarios. However the reference level and basic restriction is almost comparable in 10 MHz band and thus incident current of 20 mA would be essential to evaluate.

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