Numerical Electromagnetic Analysis of Human Exposure for Wireless Power Transfer Systems

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Introduction

This paper presents methods to demonstrate scientifically sound assessment of human exposure to wireless power transfer systems. The efficient transfer of wireless power has recently been demonstrated at distances within a few meters [2]. These systems employ strongly-coupled self-resonant coils, typically at frequencies in the 1 - 20 MHz range. People are likely to be located in the near field of these systems, so it is important to identify the conditions under which human exposure complies with international limits. Previous attempts to address exposure have been made by assessing the incident fields [4], resulting in relatively low power levels in order to comply with the reference levels. However, for such near field exposures, compliance is more accurately evaluated in terms of Specific Absorption Rate (SAR). The proposed methods are demonstrated for a representative wireless power transfer system.

Materials and Methods

The FDTD simulation platform SEMCAD X (Schmid & Partner Engineering AG, Zürich) is used, together with the Huygens box method to significantly reduce the simulation time. Four detailed anatomical human models were used for the numerical simulations of this study: a male and a female adult, an eight year old girl and a six year old boy as described in [1]. The four models were exposed to the single-sided (transmit only) wireless power transfer system operating at its simulated resonance (8 MHz). For each model, coronal, axial, and sagittal orientations of the coil were analyzed. The nearest distance between the coil and the back of the model was 10 mm.

The example wireless power transfer system studied here is shown schematically in Figure 1 [3]. To prevent the source and load from directly loading the self-resonant coils, they are coupled inductively to the coils through single turn loops. The transmit loop has an outer diameter of 30.5 cm. The transmit coil (TX) is a spiral with 6.1 turns, an outer diameter of 58 cm and a pitch of 1 cm. The loop to coil distance is 13.5 cm. The diameter of the copper wire is 2.54 mm for the coil and loop. The source resistance of the loop is 50 Ω and a matching series capacitance of 450 pF is used. The resistance of the coil was measured to be 6 Ω. This is modeled using 24 distributed resistances of 0.25 Ω each. The series capacitance of the coil is 11 pF. The model of the system was discretized using a nonuniform grid with a minimum step of 1.0 mm. The simulated system has been validated against measurements and a lumped element model.

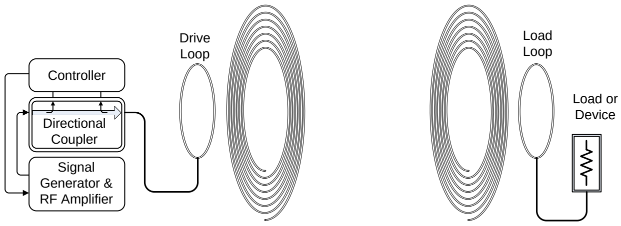

Figure 1: Schematic block diagram of magnetically coupled resonant wireless power system. A two element transmitter, comprising a loop and high-Q coil wirelessly powers a similar two element receiver. Reprinted from [3], ©IEEE.

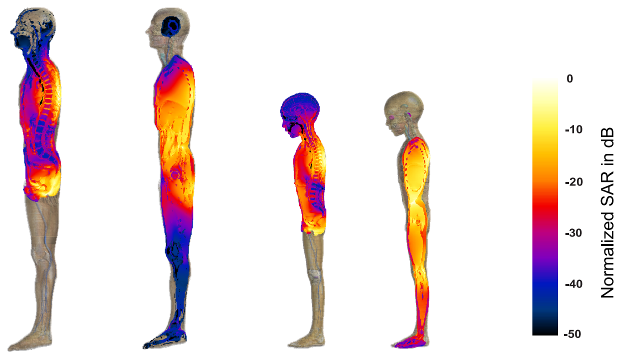

Figure 2: Local SAR in the models Duke and Thelonious in two sagittal planes (centered and 75 mm off center) for coronal exposure.

Results

Figure 2 shows the distribution of the local SAR in the bodies of the male adult model and the boy model. Whereas the peak spatial average SAR always occurs closest to the coil, the distribution in the body is strongly inhomogeneous. It can be seen that regions of high SAR can occur at larger distances from the coil. The limits are most restrictive for the coronal orientation, where the exposure limits are generally reached at currents of 0.5 A_{RMS} - 1.2 A_{RMS}, depending on the body model and SAR limit used. These currents correspond to power levels between 45 W and 280 W, using calculations described in [3]. These power levels are at least two orders of magnitude higher than the power levels estimated from the incident fields of a similar system in [4]. This provides an estimate of the transmitted power at which SAR limits are reached for this example system. The 1-gram average SAR limit from IEEE C95.1-1999 is the most restrictive limit, followed by the whole-body average SAR limit and then the 10-gram average SAR limit of ICNIRP and IEEE C95.1-2005. SAR variations among different models can exceed 3 dB for the same coil configurations.

Summary and Conclusions

This study proposes a scientifically sound method of evaluating human exposure in the reactive near field of a wireless power transfer system. To estimate the transmit power levels at which compliance with the SAR limits is achieved, an investigation of the exposure was performed under certain operating conditions. The exposure is dependent on the anatomical model, with variations exceeding 3 dB for the configurations studied. The results confirm that significantly higher transmit power levels can be used to demonstrate compliance with the basic restrictions than if the reference levels are used.

For a complete evaluation of compliance, many other important issues shall be addressed. To ensure that the evaluated exposure covers the 95th percentile of the exposed population, influences of the body posture, inner anatomy, coil distance and coil orientation shall be investigated. Variations of the system geometry and system performance shall also be investigated. A methodology with known uncertainty must also be developed.

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