Dosimetry Analysis of A 3-D Open-Structured Wireless Power Transfer System

Yaqing He, Peter S W Leung, Yuk-Tak Chow
Department of Electronic Engineering
City University of Hong Kong,
Hong Kong SAR, China
Email: yaqinghe2-c@my.cityu.edu.hk

Yinliang Diao
College of Electronic Engineering,
South China Agricultural University,
Guangzhou, People's Republic of China

***Abstract*—This paper provides a dosimetry model of a 3 dimensional (3-D) box-shaped open-structured wireless power transfer (WPT) system for mobile devices. The induced electric field in the forearm and hand of an adult male model are evaluated at 6.78 MHz with 99th percentile values as prescribed by ICNIRP. Numerical method of scalar potential finite difference (SPFD) is adopted for the dosimetry analysis; different positions of the forearm with respect to the charging system are investigated. This paper presents an explicit dosimetry model and analysis of the electric field in human forearm for a 3-D box-shaped WPT system.**

Keywords—dosimetry analysis; open-structured WPT system; induced electric field; 99th percentile value;

I. Introduction

Wireless Power Transfer (WPT) charging platforms have been well implemented for portable mobile devices in the past years. The conventional structures of the WPT platform are based on a planar configuration [1]–[3], while 3-dimentional (3-D) configurations in forms of box-shaped, bowl-shaped, and open cavity have been considered in recent years [4]–[6].

A 3-D box-shaped structure of WPT system has been recently proposed and developed at a frequency of 6.78 MHz [7]. This WPT system consists of two series-connected rectangular windings as the transmitting coils, as shown in Figure 1. This creates a homogeneous magnetic field as the orange area, inside its structure, with provision of more than one mobile device to be charged simultaneously.

The transmitting coils inside the cavity of the 3-D structured WPT system would generate intense magnetic field inside. The effective charging space, as well as the efficiency of charging, in the form of the cavity, can hence be much increased.

It is considered that due to the open-structured nature of the transmitting coils, hands and arms inside the cavity may suffer adverse health risks from electromagnetic exposure. However, it has not been sufficiently investigated yet. ICNIRP, on the other hand, provides both the basic restrictions as well as the reference level for limiting electromagnetic field exposure[8], [9], in order to provide guidance on preventing the potential risks.

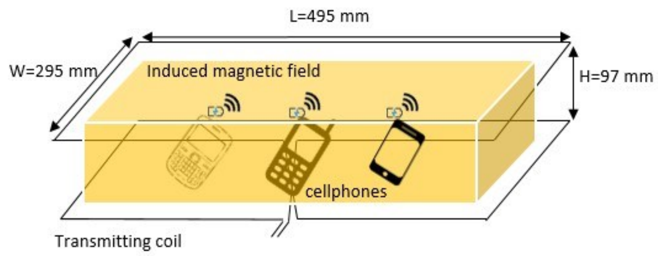

Fig. 1. Dimostration of the box-shaped 3-D open-structured WPT system. The yellow area represents the effective charging space.

The purpose of this study is to provide the dosimetry analysis of the 3-D box-shaped open-structured WPT for mobile charges by numerical method using the scalar potential finite difference (SPFD) approach, and comparing with the prescribed in the ICNIRP guidelines.

II. Models And Methods

A. Modeling of the Source

In this assessment, 1 A_{rms} current was adopted [7]. It is verified that the presence of biological tissue does not disturb with the distribution of external magnetic fields [10]; hence the magnetic field source was established in two steps - Firstly, the magnetic field distribution of the transmitting coil without human body model was evaluated using the software of ANSYS HFSS. Secondly, the corresponding vector potential *A* is derived for calculating the internal electric field induced in the human body with the method of scalar potential finite difference (SPFD) method in MATLAB.

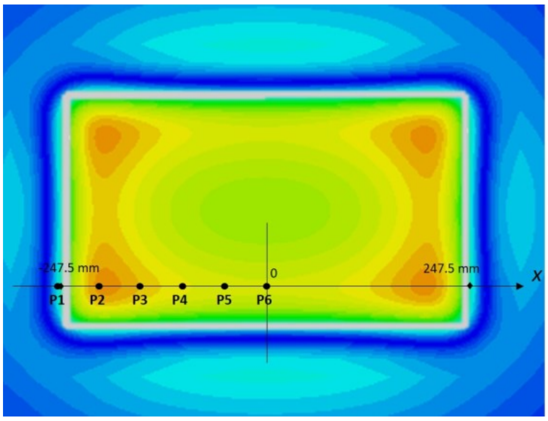

Fig. 2. The distribution of the induced magnetic field inside the transmitting coil with 1A current under working mode.

The magnetic field distribution is illustrated in Fig. 2. It could be observed that the distribution of the magnetic field is symmetric, the field strength are almost evenly distributed inside the effective charging space, except that the field strength is slightly stronger at the corners than at the center.

TABLE I. THE POSITION OF THE SELECTED SIX POINTS

Name of the point	P1	P2	P3	P4	P5	P6
The distance from the center (mm)	250	200	150	100	50	0

B. *Forearm Model*

A model of the right forearm with hand is adopted in this assessment. The model is a portion of the MRI-based whole-body voxel adult male model named Taro [11]. Taro has a height and weight of 161 cm and 53 kg respectively, and has been segmented into 51 anatomical tissues or organs, with a spatial resolution of 2 mm × 2mm × 2 mm. The posture of the forearm is adjusted using software [12] such that the forearm is parallel to the ground The tissue conductivities are adopted from [13].

Fig. 3 illustrates the exposure scenarios, the right hand - the public strong hand - reaches into the transmitting coil about 30 cm. Due to the symmetry of the transmitting coil and the positions human forearm and hand could be reached, 6 positions as summarized in table I were selected for the assessment separately.

C. *Calculation of Induced Electric Field*

In this study, the current on the transmitting coil is given as 1 A_{rms}. The 99th percentile value of internal electric field [14], which is suggested to be extended up to 10 MHz in [9], was adopted as another measurand in our assessment. This value exceed in only 1% of the voxels of that organ, which is considered a more reasonable assessment of the actual maximum field because it could prevent some errors for the modelling from voxel discretization and staircasing at sharp corners[15].

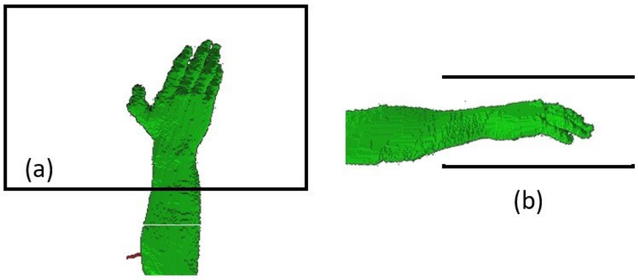

Fig. 3. Top view of exposure scenario at one position. The positions of the forearm and hand were in line with the 6 points introduced in table 1.

The electric field and the 99th percentile values in the forearm and hand were evaluated at positions from P1 to P6. The numerical method of scalar potential finite difference (SPFD) is adopted for the dosimetry evaluation of the 3-D box-shaped open-structured WPT system.

III. RESULTS AND DISCUSSION

In this preliminary study, the dosimetry analysis of the induced electric field distribution and 99th percentile values of a 3-D box-shaped open-structured WPT system for mobile charges was evaluated. The induced electric field and the 99th percentile values in the forearm and hand were evaluated at positions from P1 to P6. Fig. 4 summarizes the induced electric field distribution in the forearm and hand at 6 points.

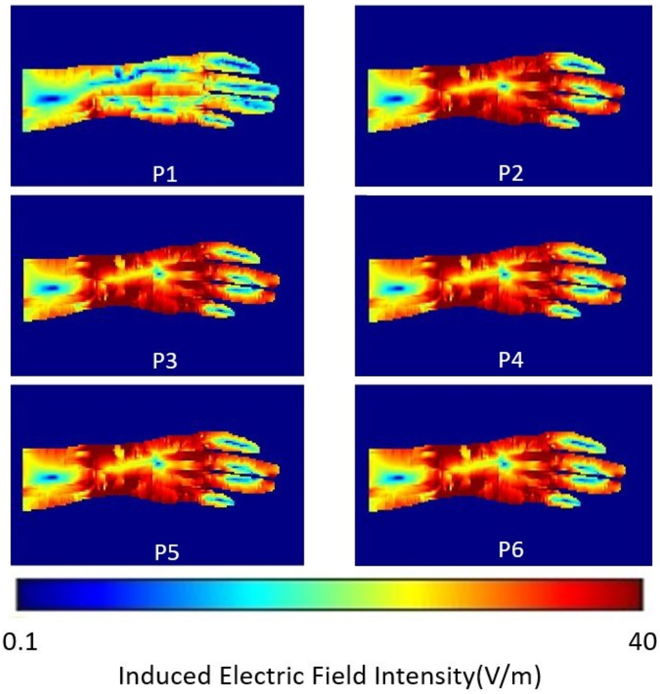

Fig. 4. Illustration of the induced electric field distribution in the forearm and hand model at 6 points.

Based on the results, the induced electric field distribution in the forearm and hand model is weak at P1, which is the farthest point from the center. The distributions at points P2 to P6 are roughly similar, and the intensity of the derived electric field is stronger in the wrist portion. Moreover, among them, the intensity of the electric field derived at P2 is much stronger than the electric field distribution derived from other points.

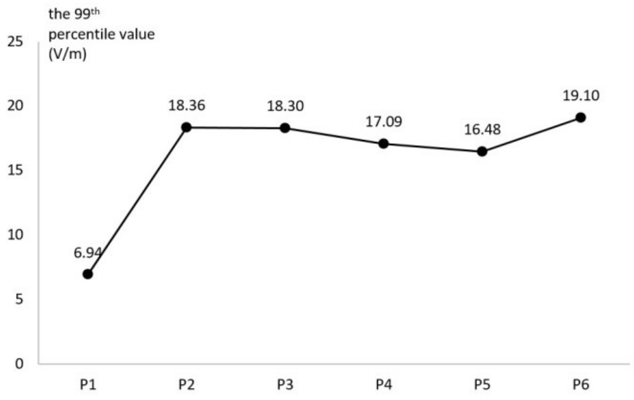

Fig. 5. Illustration of the 99th percentile values of the internal electric fields of the 6 points.

The 99th percentile values of internal electric field were then calculated, and the results are illustrated in Fig. 5. As illustrates, the maximum value shows the center of the coil, due to the homogeneousness of the magnetic field around P6; the minimum value is at P1. Noted that the second higher value of the 99th percentile appears at P2, where the intensity of the magnetic field intensity is the highest while the gradient at P2 is larger than other points. In ICNIRP 2010 [9], the basic restriction value of induced electric field for the public at the frequency of 6.78MHz is specified as 915 V/m accordingly, of which the maximum value at P6 only takes 2.09%. all E fields are lower that the basic restriction prescribed in the ICNIRP 2010 guideline.

In this analysis, the human model is preliminarily adopted from an adult male model without any charging devices. Different body models of two genders and various ages, with wirelessly chargeable devices will be further investigated. Besides, previous research [10], [16] have recommended that the specific absorption rate (SAR), rather that the internal electric field, is the more conservative parameter at the frequency of 6.78 MHz; and the 99.9th percentile value has been introduced [17] as a more satisfactory metric for removing the errors caused by the voxel discretization or segmentation of some tissues. These two metrics will also be taken into our consideration for the analysis in the future.

IV. CONCLUSION

This paper provides a dosimetry analysis of a 3-D box-shaped open-structured WPT system for mobile charges. The induced electric field distributions as well as the 99th percentile values of internal electric field are evaluated at 6.78 MHz with a nominal charging current of 1 A_{rms}. This paper illustrates the dosimetry modelling of the electric field in human forearm inside a 3-D box-shaped WPT system, and provides a method for designing such charging systems with consideration of exposure compliance. Different body models with wearable devices, as well as the other dose metrics, will be investigated in the future.

ACKNOWLEDGMENT

The work described in this paper was fully supported by the form General Research Fund of Hong Kong Government. [Project # 9042343 (CityU 11254616) - Study of human brain wave for neuro-psychological changes due to electromagnetic exposure].

REFERENCES

[1] S. Y. Hui, "Planar wireless charging technology for portable electronic products and Qi," *Proc. IEEE*, vol. 101, no. 6, pp. 1290–1301, 2013.

[2] Y. Diao, Y. Shen, and Y. Gao, "Design of coil structure achieving uniform magnetic field distribution for wireless charging platform," *2011 4th Int. Conf. Power Electron. Syst. Appl. PESA 2011*, pp. 1–5, 2011.

[3] J. J. Casanova, Z. N. Low, and J. Lin, "A loosely coupled planar wireless power system for multiple receivers," *IEEE Trans. Ind. Electron.*, vol. 56, no. 8, pp. 3060–3068, 2009.

[4] J. Kim, D. H. Kim, J. Choi, K. H. Kim, and Y. J. Park, "Free-positioning wireless charging system for small electronic devices using a bowl-shaped transmitting coil," *IEEE Trans. Microw. Theory Tech.*, vol. 63, no. 3, pp. 791–800, 2015.

[5] C. Chen, X. Wang, and M. Lu, "Wireless charging to multiple electronic devices simultaneously in enclosed box," *2016 Asia-Pacific Int. Symp. Electromagn. Compat. APEMC 2016*, vol. 01, pp. 88–90, 2016.

[6] K. Sergkei, P. Lombard, V. Semet, B. Allard, M. Moguedet, and M. Cabrera, "The Potential of 3D-MID Technology for Omnidirectional Inductive Wireless Power Transfer," in *2018 13th International Congress Molded Interconnect Devices (MID)*, 2018, pp. 1–6.

[7] J. P. W. Chow, H. S. H. Chung, L. L. H. Chan, R. Shen, and S. C. Tang, "Optimal Design and Experimental Assessment of a Wireless Power Transfer System for Home-cage Monitoring," *IEEE Trans. Power Electron.*, pp. 1–1, 2019.

[8] International Commission on Non-Ionizing Radiation Protection, "ICNIRP Guidelines for Limiting Exposure to Time-Varying Electric, Magnetic and Electromagnetic fields," *Health Phys.*, vol. 74, no. 4, pp. 494–522, 1998.

[9] International Commission on Non-Ionizing Radiation Protection, "ICNIRP Guidelines for Limiting Exposure to Time-Varying Electric and Magnetic Fields (1 HZ – 100 kHZ)," *Health Phys.*, vol. 99, no. 6, p. 818-836, 2010.

[10] T. Sunohara, A. Hirata, I. Laakso, V. De Santis, and T. Onishi, "Evaluation of nonuniform field exposures with coupling factors," *Phys. Med. Biol.*, vol. 60, no. 20, pp. 8129–8140, 2015.

[11] T. Nagaoka *et al.*, "Development of realistic high-resolution whole-body voxel models of Japanese adult males and females of average height and weight, and application of models to radio-frequency electromagnetic-field dosimetry," *Phys. Med. Biol.*, vol. 49, no. 1, pp. 1–15, 2004.

[12] T. Nagaoka and S. Watanabe, "Voxel-Based Variable Posture Models

of Human Anatomy," *Proc. IEEE*, vol. 97, no. 12, pp. 2015–2025, Dec. 2009.

[13] S. Gabriel, R. Lau, C. G.-P. in M. & Biology, and undefined 1996, "The dielectric properties of biological tissues: III. Parametric models for the dielectric spectrum of tissues," *iopscience.iop.org*.

[14] T. W. Dawson, K. Caputa, and M. A. Stuchly, "Electric fields induced in humans and rodents by 60 Hz magnetic fields," *Phys. Med. Biol.*, vol. 47, no. 14, p. 313, Jul. 2002.

[15] P. Dimbylow, "Development of pregnant female, hybrid voxel-mathematical models and their application to the dosimetry of applied magnetic and electric fields at 50 Hz," *Phys. Med. Biol.*, vol. 51, no. 10, pp. 2383–2394, May 2006.

[16] X. L. Chen *et al.*, "Human Exposure to Close-Range Resonant Wireless Power Transfer Systems as a Function of Design Parameters," *IEEE Transactions on Electromagnetic Compatibility*, vol. 56, no. 5. pp. 1027–1034, 2014.

[17] I. Laakso and A. Hirata, "Evaluation of the induced electric field and compliance procedure for a wireless power transfer system in an electrical vehicle.," *Phys. Med. Biol.*, vol. 58, no. 21, pp. 7583–93, 2013.