Note Variation of the Spatial-Average 99th Percentile Induced Electric Field in the Infant Body due to Influence of the Adult Using Ellipsoidal Models with 50 Hz Uniform Magnetic fields

Consheng Li*[1,2], Tongning Wu[1], Bingsong Lu[1], Yi Xie[1]

[1] China Academy of Telecommunication Research of Ministry of Industry and Information Technology, No.52, Huayuanbei Road, Haidian District, Beijing, China. 100191. toniwoo@gmail.com

[2] Department of Computer and Communication Engineering, University of Science and Technology Beijing, No.30, Xueyuan Road, Haidian District, Beijing, China. 100191. congshengli@gmail.com

lubingsong@catr.cn

xieyi@catr.cn

Abstract

Human exposure to low frequency (LF) magnetic fields (MF) is frequently evaluated according to ICNIRP guidelines. Standing adults are used to determine the compliance of the standards. Nevertheless, the conservativeness of the standard for the other populations, such as the minors, has been questioned and investigated by various studies using the realistic or symbolized human models. Meanwhile, the dosimetric variation of the different postures is also evaluated. In this paper, we will use the symbolized ellipsoidal models to simulate a carrying-a-baby posture and to calculate the variation for the induced electric fields. The results demonstrate that the influence by the adult (specifically, holding a baby in arms) may significantly increase the maximum induced electric fields strength (99^{th} percentile spatial-average value, E_{99}) in the infant body. Physical contact on different body levels has significant impact on the induced electric fields. The results indicate that the influence by the adult is a key factor when assessing the infant exposure to the LF MF. This effect should be explored fully in formulating the safety standard.

1. Introduction

Human exposure to low frequency (LF) magnetic fields (MF) has been discussed extensively along with the booming of the electronic devices in daily life. International Commission on Non-Ionizing Radiation Protection (ICNIRP) has drafted the guidelines to limit the emission from this kind of devices. Two guidelines have thus been published in 1998 [1] and 2010 [2]. Both of the two guidelines use the reference levels – basic restrictions to regulate the emission. They assume that the compliance with the reference levels demonstrates the compliance with the basic restrictions. The difference between the two guidelines exists in the selection of the basic restrictions. In the guidelines of 1998, the maximum current density (J, averaged over $1\,cm^2$ area perpendicular to the electric current) is utilized as the basic restriction whilst in the new guidelines of 2010, the maximum induced electric field (E_{99}, 99^{th} percentile value, averaged over a cube of 2mm x 2mm x 2mm) is the basic restriction.

In contrast, the reference level for the human exposure to uniform LF MF is defined as the external MF strength. Simulations with adult anatomical models in a standard standing posture were used to establish the relationship between the external magnetic fields and the induced electric fields. In this circumstance, concerns for the conservativeness of the guidelines for the other populations as well as the other postures inspired many studies. For example, child, pregnant with fetus and infant's exposure to the LF MF was published [3-5]. Studies focusing on the maximum internal current density showed that this metric was marginally influenced by the different postures [6]. Besides of these particular postures, there is a special exposure scenario for the infant, which is the infant in the arms of the adults. Theoretically, the influence by contacting with the dielectric objects may affect the induced electric fields. Hence, in this manuscript, we will analyze the dosimetric variation due to the influence by the adult using the symbolized human models. The exposure scenario is the 50 Hz uniform MF exposure, which may associate with the childhood leukemia [7].

2. Methods and Materials

2.1 Symbolized human models

Generating a realistic holding-a-baby posture with the adult and the infant anatomical models is time- and energy- consuming. To simplify the simulation scenario within an acceptable uncertainty, we choose the homogeneous ellipsoidal models to represent the adult and the infant. Homogeneous models of spherical or ellipsoidal shape are often used for modeling the human body exposed to EMF from the LF to RF [8-10]. The disadvantages of the symbolized

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models include their difficulties in representing specific postures, different grounding patterns and internal anatomical structure [11]. Nevertheless, symbolized models are valuable in assessing the human exposure to EMF because they often provide an insight into the qualitative nature of the coupling mechanisms [11].

In this research, we constructed two ellipsoidal models. The bigger model with long-axis as 1.70 m and short-axis as 0.42 m simulates an adult whist the smaller model with long-axis of 0.765 m and short-axis as 0.21 m simulates an infant. In order to realize the carrying-a-baby posture, we also designed two typical configurations: the adult holding the infant at its waist (baby's abdomen touching the adult's chest, as Belly_Contact in the following sections) and at its shoulder (baby's head touching the adult's head, as Face_Contact in the following sections). All the abovementioned symbolized models were shown in Figure 1.

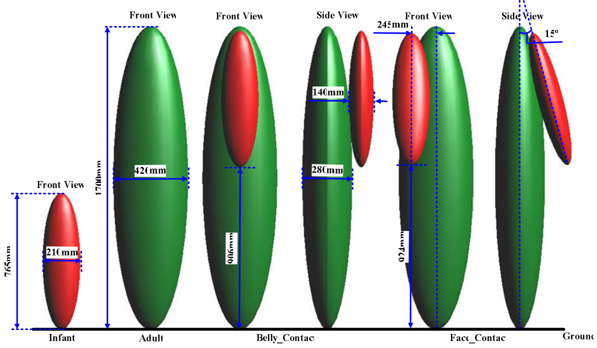

Figure 1 Symbolized models and two simulated configurations

2.2 Computation method

Numerical analysis of LF EMF exposure is frequently based on the quasi-static approximation (QSA), which has been extensively applied up to a few tens of megahertz. According to this approach, the analysis of the interactions between biological systems and LF EMF can be significantly simplified if the dimensions of the involved objects and their mutual distances were be marginal when compared to the exposure wavelength in vacuum [12]. In this case, the displacement currents in the exposed object can be assumed to zero.

Scalar potential finite element (SPFE) method [13, 14] is frequently utilized in the QSA calculation. In the present research, the calculation algorithm was realized on the platform of SEMCAD X 18.4 (SPEAG AG, Zurich, Switzerland). The voxelized dimensions were $1\,\text{mm}\times 1\,\text{mm}\times 1\text{mm}$. E_{99} was calculated in the cubic volume of $2\,\text{mm}\times 2\,\text{mm}\times 2\text{mm}$.

2.3 Exposure scenarios

We focused on the uniform 50 Hz MF exposure in this study. Therefore, the corresponding field distribution should be realized. The parallel power lines method as described by [15] was applied; two parallel power lines with a length of 10 mm and a separation of 10 mm were introduced in the calculation volume. The current in these power lines had equal values but different directions. These power lines were placed in the x-y, y-z and x-z planes, respectively. The long-axis of the ellipsoidal human models was perpendicular to the x-y plane and grounded. A distance as 100 m was kept between the power lines and the human model. All the models shown in Figure 1 were involved in the numerical simulation.

3. Results

E_{99} is shown in Figure 2 for each simulated model and specific magnetic field incident direction.

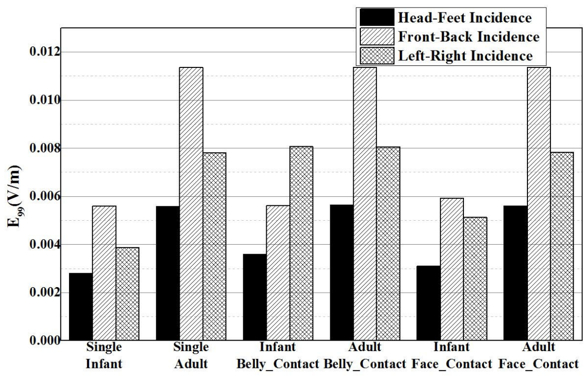

Figure 2 E_{99} for the different models and with different postures (B=2×10^{-4} T)

According to Faraday's law of induction, the induced electromotive force (but not necessarily the E_{99}) are proportional to the cross sectional area of the conductor. Therefore, it is therefore essential to present the effective maximum connected cross sectional area for all the models, incident directions and the postures. The results are listed in Table 1

Table 1 Maximum connected cross sectional area for the simulated models/postures. The area is calculated for the projection on the three distinctive planes. All the models are standing and grounded on the X-Y plane. The Front-Back direction in Figure 1 corresponds to the negative to the positive direction of X axis.

		X-Y plane (m^2)	X-Z plane (m^2)	Y-Z plane (m^2)
Infant		2.2944E-02	1.2568E-01	8.3608E-02
Adult		9.1812E-02	5.5810E-01	3.7151E-01
Total Belly_Contact *		1.0002E-01	5.5818E-01	4.5435E-01
Belly_Contact	Infant	1.6232E-02	5.5810E-01	8.3612E-02
	Adult	8.3792E-02	5.5818E-01	3.7074E-01
Total Face_Contact*		9.1920E-02	5.5823E-01	3.7535E-01
Face_Contact	Infant	2.3712E-02	7.2948E-02	4.4020E-02
	Adult	9.1920E-02	5.5823E-01	3.3133E-01

* indicates the total connected cross sectional area which is the sum for that from the adult and the infant

4. Discussions

Homogeneous ellipsoidal models feature with their regular contours and the simple internal structures. Therefore, the dosimetric influence by the individual localized physical feature and the local dielectric distribution can be eliminated. We could focus on the study for the effect by the models' physical dimensions.

Larger ellipsoidal model has always higher E_{99} in comparison with the smaller one when exposed to the same MF. The effect can be explained by the respective cross sectional area perpendicular to the incidence of the MF. Similar reason can also account for the reason why the front-back incidence produced higher E_{99} compared with the other two incident directions. Table 1 supported the assumption by showing that the cross sectional area projecting on the X-Z plane (front-back incidence) was larger than on the other two planes.

An interesting effect can be found with the posture of "Belly_Contact". The E_{99} results from the smaller model with the Left-Right and the head-feet incidences are higher than those of the smaller model. For example, the E_{99} doubles with the Left-Right incidence. This is attributed to the enhancement of the cross sectional area by the physical contact with the larger model. Face_Contact induces a moderate increase for the cross sectional area and the level of raised E_{99} is higher than the smaller ellipsoidal model but less than the Belly_Contact configuration. In contrast, the Front-Back incident case will not increase the cross sectional area since the smaller model is just in front of the larger one. The explanation is supported by Table 1, which documents the individual cross sectional area for each simulated postures.

Results from the study indicate that the influence by the adult may significantly increase the E_{99} in the infant due to the enlarged cross sectional area by physical contact. The effect needs further investigation with the realistic anatomical models to consider the effect by specific anatomy and the various postures. The current safety recommendations on LF EMF exposure should take into consideration for this effect and be revised accordingly if necessary.

E_{99} is related but not equivalent to the induced electromotive force, which is in direct correlation with the time-varying MF exposure. So no simple linear relation is found between the E_{99} and the cross sectional area. We found the increase of E_{99} occurred only in the smaller model. The mechanism should be studied in the following work.

5. Conclusion

The work studies the variation of the E_{99} in the infant's body due to the influence of the adult using symbolized ellipsoid models. The aim of the research is to investigate whether the carry-a-baby posture by the adult can influence the E_{99} in the infant or not. The symbolized ellipsoidal models are reconstructed to simulate the infant and the adult. Two typical postures as belly_contact and face_contact are simulated with the exposure of 50 Hz uniform MF exposure from three orthogonal directions. The results confirm that the cross sectional area is an influential factor to the E_{99}. In particular, the physical contact with the adult may increase the connected cross sectional area and thus significantly raise the E_{99} in the infant. The effect needs further investigation in the further revision of the safety recommendations on LF MF exposure.

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