Comparison of Induced Ankle Currents of the Human-Body Equivalent Antennas and Anatomically Human Models Exposed to Nearby Monopole Antennas

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Abstract

In this paper, the induced ankle currents of the liquid-type human-body equivalent antennas are compared to those of their corresponding Japanese adult male and female models when exposed to monopole antennas placed at a distance of 3 m away. The purpose is to determining if they will be in good agreement like the case of plane wave exposure from which they were designed. The investigation of the monopole antennas exposure is important, because they have been used to provide experimental validation of the performance of the equivalent antennas. Our results indicate that good agreement in induced ankle current is obtained for the frequencies above 45 MHz. This may be explained by the fact that at the frequencies above 45 MHz, at 3 m distance away, the equivalent antennas appear to be at far fields of the monopole antennas, at which the fields becomes almost like those of the plane wave.

1. Introduction

At Very High Frequency (VHF) bands (30-300 MHz) the power absorption by the human body due to RF exposure reaches maximum values. This is because the whole-body resonant absorption frequencies lie within this region [1]. It is known that large current flows at the ankle if the human body stands on the ground at the whole-body resonant condition. The local SAR around the ankle (SAR ankle) can be estimated from the induced ankle current (I_ankle) and the equivalent section area of the ankle (A_ankle), i.e., SAR_ankle = (I_ankle/A_ankle)2/sigma. As a result, the induced ankle current is used as an additional exposure limit in the VHF bands in the ICNIRP and IEEE guidelines. The liquid-type human-body equivalent antenna that can be used for measuring these currents has been previously proposed [2]. The antennas consist of acrylic rectangular blocks and metal plate, which are filled with NaCl solution and connected together using conducting pins. While we have conducted detail investigation of the induced currents of the equivalent antennas using plane wave exposure, and validated our numerical calculations using experimental results obtained when the antennas are irradiated with nearby monopole antennas, there have been no investigations to compare the induced ankle currents of the equivalent antennas and their corresponding human model so far. This is important because, we have been using monopole exposures to validate our numerical assumptions. In this paper we consider equivalent antennas for adult Japanese male and female models [3]. The induced ankle currents are calculated using non-uniform mesh FDTD analysis to minimize computer resources [4].

2. Equivalent Antennas and Method of Calculation

2.1 Equivalent Antennas

Fig.1 shows the structures of the liquid-type human-body equivalent antennas for the adult male and female Japanese models [3]. The equivalent antenna for the adult male model is made up acrylic blocks placed on top of metal plate; they are connected together using conducting pins. Antenna for female model is made up of 5 blocks. The antennas are filled with NaCl whose electrical properties are obtained by measurements. The electrical properties of the liquid used are listed in Table I. It should be noted here that, the electrical properties of the human models were derived from Gabriel reports [5].

TABLE I: ELECTRICAL PROPERTIES OF THE NaCl SOLUTION USED IN EQUIVALENT ANTENNAS WITH CONCENTRATION OF 2.7 %

f [MHz]	30	40	45	60	80	100
ε_r	86.4	85.2	84.7	83.5	81.7	80.7
σ[S/m]	4.04	4.05	4.06	4.07	4.09	4.09

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2.2 Method of Calculation

The non-uniform mesh FDTD technique was used in this investigation to minimize computer resources. This technique, which is based on Maxwell's curl equations represented by midpoint method and Yee-cell notation, utilizes either a linear or quadratic interpolation at the coarse-fine cell boundary to reduce reflection errors [4].

Throughout this work, a fine-size cells of $\Delta x = \Delta y = \Delta z = 2$ mm were used to model the regions around the monopole antennas and human model. Other areas of the FDTD problem space were modeled with coarse-size cells of 20 mm in all directions. During equivalent antenna calculations, a fine-size cells of $\Delta x = \Delta y = \Delta z = 5$ mm were used. The coarse-size cell must be $\leq \lambda/15$, where λ is the free space wavelength.

Beranger's perfect matched layer (PML) [6] having 8 layers and $M = 4$ are placed at all boundaries of the FDTD problem space to absorb the radiated outgoing waves. Metallic structures such as ground plane, equivalent antenna metallic plate and connecting pins, were modeled as a perfect electric conductor (PEC) by setting all of their E-fields to be equal to zero.

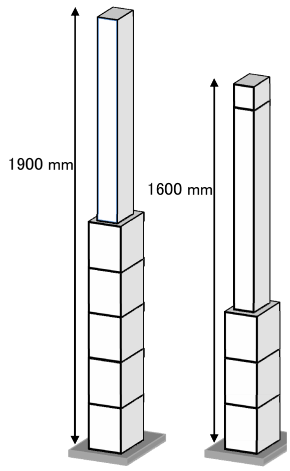
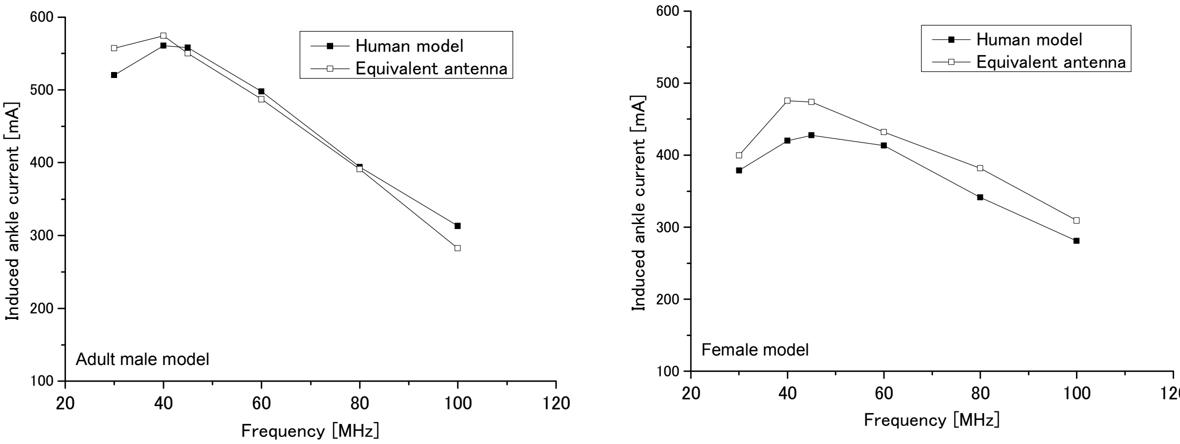
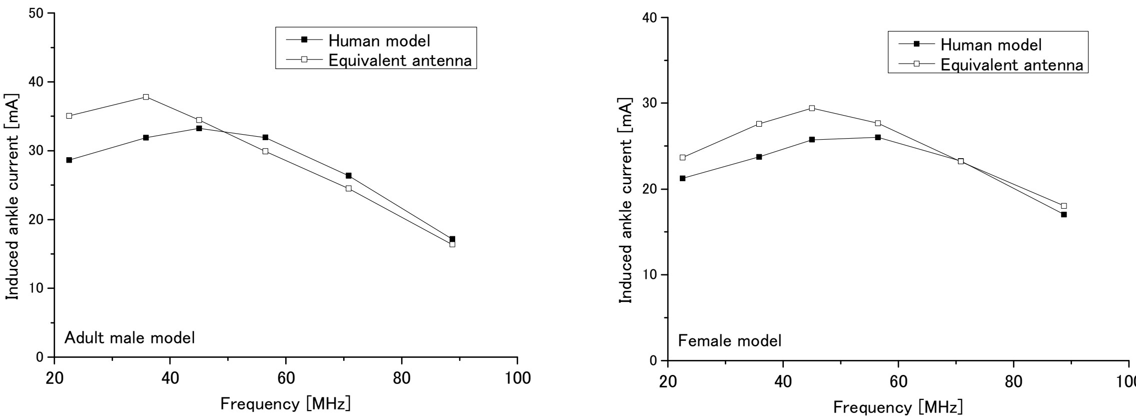


Fig. 1 Liquid-type human-body equivalent antennas. From left to right: Antenna for adult male, and female



(b) Adult male (b) Female

Fig. 2. Frequency characteristics of the induced ankle currents of the human models and their equivalent antennas when exposed to plane wave exposure. (a) Adult male, and (b) Female



(a) Adult male (b) Female

Fig. 3. Frequency characteristics of the induced ankle currents of the human models and their equivalent antennas when exposed to nearby monopole antennas. (a) Adult male, and (b) Female

TABLE II: FAR FIELD DISTANCE OF MONOPOLE ANTENNAS AT A GIVEN FREQUENCY

f [MHz]	28.6	35.740	45.0	56.5	70.9	88.8
d [m]	5.3	4.2	3.3	2.7	2.1	1.7

3. Results and Discussions

Fig. 2 compares the induced ankle currents of the equivalent antennas and their corresponding human model when exposed to E-polarized plane wave exposure. We observed good agreement between the results with maximum difference of less than 10-% [2].

Comparison of the induced ankle currents for monopole antennas exposure is given in Fig.3. They were exposed by monopole antennas operating at 28.6, 35.7, 45.0, 56.5, 70.9, and 88.8 MHz. We observed large differences at lower frequencies, for example the difference of 12.5, 14.4 and 10.3% were recorded at the frequencies of 28.6, 35.7 and 45.0 MHz, respectively, for the female model. These large differences, at these frequencies, may be explained by the fact that for the distance of 3 m from monopole antennas, the equivalent antennas are in fact in the near field region of the monopole antennas. This can be argument may be support by calculating the far field distance of the antennas as indicated in Table. For the far field condition of the of the monopole antenna to be satisfied the distance d must satisfy the equation: $d \geq 2 \cdot D^2 / \lambda$.

We can clearly see in Table II that for the frequency below 45 MHz, the equivalent antennas are in the near field.

5. Conclusion

In this paper, we have compared the induced ankle currents of the liquid-type human-body equivalent antennas and their corresponding Japanese adult male and female models. We have found that good agreement is obtained when the equivalent antennas are placed at a distance such that they are in the far field of the monopole antennas. At the far field of the monopole antennas the exposure field may be similar to the plane wave exposure, which was used in the design of the equivalent antennas.

6. Acknowledgments

Calculations in this work have been conducted using the supercomputer (NEC/SX-8R) at the National Institute of Information and communications Technology.

7. References

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