Foot Currents Induced in Human Bodies Exposed to a Cellular Phone Base Station

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ABSTRACT

Currents induced in human feet near a cellular phone base station were calculated by the finite-difference time-domain (FDTD) method and measured by a parallel plate meter at 1869 MHz. From simulation results and measurement data, it is found that the theory of FDTD method makes a good agreement with the experiment. It is also found that the maximum foot currents of 20.73 and 18.51 milliamps were obtained by measurements and calculations when a human stands barefoot at a distance of 10 meters from the cellular phone base station, respectively. From measurements and calculations, the foot currents are reduced by a factor of about 0.72~0.91 and 0.8 when the condition is changed from standing barefoot to wearing shoes, respectively.
Keywords Cellular phone base station, foot currents, parallel plate meter, FDTD.

I. INTRODUCTION

In recent years, there has been an increasing trend to set up more cellular phone base stations for GSM and the latest 3-G developments. However, the worldwide popularity of cellular phone base station antennas has caused public concerns regarding potential health hazards due to radiofrequency (RF) energy absorbed in human bodies. Public concerns are focused on the biological effects produced in human bodies due to long-term exposure to RF fields at high frequencies and exposure levels. RF energy may result in high levels of induced currents through a human body when close to cellular phone base station antennas. Because of its relationship to the specific absorption rate (SAR) in the human body, the induced currents passing through a human body is an important parameter for assessment of potential health hazards. The SAR in the human body can also be related directly to the local current density. For frequencies below 300 MHz, several theoretical and experimental evaluations of the currents induced in the human body exposed to electromagnetic (EM) fields have been reported in the literature. However, there is still a great deal unknown about the current induced in a human body due to the exposure of EM fields for frequencies over 300 MHz. Therefore, it is important for researchers to study theoretical and experimental quantification of currents induced in human bodies exposed to EM fields for frequencies over 300 MHz. In this paper, the finite-difference time-domain (FDTD) method [1] was chosen because the method can be applied easily to complex configurations and needs smaller computer storage. Current distributions in human bodies exposed to cellular phone base station antennas were calculated by the FDTD method at 1869 MHz. Currents induced in both feet computed by the FDTD method are also presented and compared with those obtained by measurement. For measurements of induced body currents near a cellular phone base station, a platform is placed on the surface (where a person stands), and the person is placed on the upper plate of the platform. A voltage drop on a low-inductance resistor of 50 Ohms placed between the plates provides a measure of the induced current.

II. THE FINITE-DIFFERENCE TIME-DOMAIN METHOD

The basic FDTD method was first proposed by Yee [1] and later developed by many researchers for antenna analysis, EMI/EMC, shielding applications, microwave engineering, bio-electromagnetic, and many electromagnetic problems. In the FDTD solution procedure, the coupled Maxwell's equations in differential form are solved for various points of the object as well as its surrounding in a time-stepping manner until converged solutions are obtained. Following Yee's notation and using centered difference approximation on both the time and space first-order partial differentiations, six finite-difference equations for six unique field components within a unit cell are obtained. In these six finite-difference equations, electric fields are assigned to half-integer (n+1/2) time steps and magnetic fields are assigned to integer (n) time steps for the temporal discretization of fields. To ensure numerical stability, the time step δ_t is set to $\delta/(2C_o)$, where δ and C_o are the cell size and the speed of light, respectively. The center difference approximation ensures that the spatial and temporal discretizations have second-order accuracy, where errors are proportional to the square of the cell size and time increment [1]. An important problem encountered in solving the time-domain electromagnetic-field equation, by the FDTD method, is the absorbing boundary conditions. In our formulation, the second-order Mur approximation of absorbing boundary conditions [2] is used for the near-field irradiation problems. We employ the second-order Mur absorbing boundaries because they do not require much memory and have a reasonable accuracy. The external absorbing boundaries are placed at a distance of 6 δ on all sides of the scattering object, where δ is the cell size. The details of the FDTD method may be found in many publications and will therefore not be repeated here.

III. SIMULATION RESULTS AND MEASUREMENT DATA

The human body was modeled by a homogeneous model with 2,100,000 cubic cells of 5 mm on each side. The dielectric constant and conductivity of muscle tissue are adopted for simulations of the homogeneous human model. At 1869 MHz, the relative dielectric constant and conductivity of the homogeneous human model are chosen to be ε_r=53.5, σ= 1.34 S/m, respectively [3]. A sinusoidal plane wave with an electric field by $E_z = E_0 \sin 2\pi\omega t$ is adopted as the incident wave, where E_0 and ω are the amplitude of the electric field and the angular frequency, respectively. Electric field strengths E_0 of the incident waves were adopted by measurement data obtained at 1.0 meter above the flat roof-floor of a seven-story building. The seven-story building has a height of 28.21 meters above the ground plane and the flat roof-floor is constructed with reinforced concrete material. Measurements of the field strengths were obtained by using a Narda Model NBM-550 digital electromagnetic field survey meter [4]. The Model NBM-550 with field probe Model EF0391 is designed to measure RF fields over a frequency range from 100 kHz to 3.0 GHz.

The foot currents were measured using a parallel plate meter at 1869 MHz. The geometrical structure of the parallel plate meter was made of two aluminum plates, wood, copper foils, and a resistor as shown in Fig. 1. The upper and lower plates have a size of 900 and 2500 cm^2 with a thickness of 2 mm and are separated by 4 cm, respectively. The copper foils with a thickness of 0.13 mm were pasted on the aluminum plates. The resistor of 50 Ohms was connected between the two aluminum plates for measuring the induced currents flowing through the ground by an Anritsu spectrum analyzer MS2721A. For measurements of foot currents, the lower plate was connected to the ground. Before measuring, the calibration of the parallel plate meter was checked using an Anritsu signal generator MG 3694B and an Anritsu spectrum analyzer MS2721A as shown in Fig. 1. On the flat roof-floor of the seven-story building, there are 6 measurement locations on the roof-floor for measuring foot currents.

Foot currents were measured when a man was standing on the parallel plate meter in conditions of wearing shoes and standing barefoot. Theoretical calculations of induced currents were done by the FDTD method. In order to simulate a human model standing on a conducting parallel plate meter, the image theory can be used to obtain FDTD method solutions of induced currents in a human body [5].

Applying the image theory in the FDTD simulations, the incident waves propagate parallel to the conducting plate and have an electric field polarized perpendicular to the conducting plate. As the internal electric fields in the human body are calculated by the FDTD method, the internal electric fields can be used to calculate the local current densities at each cell from the relationship

$$\bar{J} = [\sigma + j\omega\varepsilon_0(\varepsilon_r - 1)]\bar{E} \quad (1)$$

where $\bar{E}$ is the electric field within the human body, ω is the angular frequency, and σ and ε_r denote the conductivity and relative dielectric constant of the human body, respectively. The first term of equation (1) is the conduction current and the second term represents the polarization current. The induced currents for any of the layers are obtained by summing the terms due to the individual cells in a given layer as following:

$$\bar{I} = \delta^2 \sum_{\mathrm{i}} \bar{J}_{\mathrm{i}} \quad (2)$$

where δ^2 is the cross sectional area for each of the cells.

The foot currents measured at these six measurement locations on the roof-floor are presented in Table 1, where the foot currents calculated by the FDTD method are also used as a comparison to the parallel plate meter at 1869 MHz. From Table 1, it is shown that good agreement is obtained between the measurement data and the calculation results. The maximum measured current passing through both feet is 20.73 milliamps, and this maximum is at 10 meters from the cellular phone base station. Within 10~30 meters from the cellular phone base station, the average foot currents is less than 11.07 milliamps. Wearing shoes can reduce the foot current. A current reduction factor is defined by I_s/I_b, where I_s is the current when the human is wearing shoes and I_b is the current when the human is standing barefoot. It is found that a reduction factor of 0.72~ 0.91 and 0.8 are observed from measurements and the FDTD method, respectively.

IV. CONCLUSIONS

The FDTD method has been used to calculate the current induced in human bodies near a cellular phone station at 1869 MHz. A parallel plate meter is also designed to measure the current flowing from the feet to the ground for a human body near a cellular phone station. From simulation and measurement results of foot currents, it is found that the theory makes a good agreement with the experiment. From simulation and measurement results, it is found that most foot currents are below 21 milliamps when a man stands near the cellular phone base station at a distance of 10~30 meters from the base station. It is also found that the foot currents decrease gradually with distance from the cellular phone base station increases. From measurements and simulations, the foot currents are reduced by a factor of 0.72~0.91 and 0.8 when a man wears shoes, respectively. The FDTD method offers the possibility of obtaining current distributions in human bodies and provides a simple and inexpensive method to evaluate SAR distributions for various standards and safety guidelines.

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Table 1 Measurements and calculations of foot currents at 6 locations for a man wearing shoes and standing barefoot. The unit of induced currents is in milliamps.

Locations	1(10m)	2(10m)	3(10m)	4(20m)	5(20m)	6(30m)
Wearing shoes (Measurement)	9.37	16.58	10.59	10.38	8.00	4.15
Wearing shoes (FDTD)	9.31	14.90	11.55	11.08	8.57	4.84
Barefoot (Measurement)	10.10	20.73	12.76	11.43	11.16	5.32
Barefoot (FDTD)	11.57	18.51	14.35	13.77	10.65	6.02

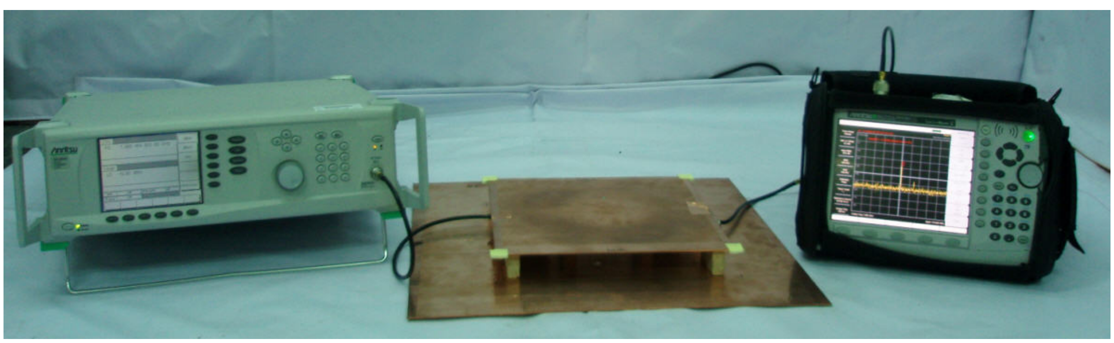

Fig. 1 Calibration of the parallel plate meter