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Numerical Computing of Reduction of SAR Values in a Homogenous Head Model Using Copper Shield

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***Abstract*— In this study, variation of the maximum specific absorption rate (SAR) on mobile phone user was researched when mobile phone was shielded with copper at 900 MHz frequency. Simulations were conducted to calculate the maximum SAR values in Matlab programming language using 2D-FDTD (Finite Difference Time Domain) method. Calculations were made separately for 1g and 10g. Head structure was assumed to be uniform.**

***Index Terms*— FDTD, Mobile phone radiation, Numerical computation, SAR, Shielding.**

I. Introduction

Today mobile phones are one of the most widely used electronic equipments. In addition, it has a large number of users regardless of age. For this reason, designing of mobile phones which do not adversely affect human health is providing great importance.

So far, effects of mobile phones and other devices emitting electromagnetic waves on human health and measures against them have been investigated and still continue. As the results were evaluated, 1 °C temperature increase of tissue cannot be removed in the circulatory system and this damages tissue. Limits for each frequency band were specified by the relevant institutions according to this case. Limits for the general public in the SAR value are 0.08 W/kg at 10 MHz-10 GHz frequency band [1]. SAR (W/kg) is the amount of the power absorbed by unit weight tissue. Measuring of SAR values in living cells is not experimentally possible. Specifically created model is used for this. SAR values can be measured experimentally by placing probe into the model.

Determination of SAR values can also be carried out with numerical calculations as an alternative to using the model [2]-[5]. In this method, the calculations are carried out by using electrical properties and physical dimensions of the typical human head.

Used mobile phones are manufactured within the specified limit values. However, negative consequences that may occur can be seen in time due to placing them close to head during the use of mobile phones and due to long phone calls. In this case, it is required to use with precautions. For instance, a headset-microphone set can be used while using. Thus, the electromagnetic wave exposed to user head will be less.

In addition, the attenuation of electromagnetic waves emitted from mobile phone towards user's head by using the conductive material can be provided. Conductive material mostly reflects the electromagnetic waves back. Thus, the amount of absorption of electromagnetic waves will be reduced to minimum level by placing the suitable sized conductive plate between the mobile phone's antenna and the user head.

In this study, two dimensional simulations have been conducted to investigate reducing of SAR values on user head by using copper plate. Simulations have been carried out in Matlab programming language using the 2D-FDTD method. First order Mur boundary conditions have been used to remove artificial reflections naturally occurred in FDTD method. The reason for choices of 2D and Mur boundary conditions in the simulation are to keep computer memory and processor requirements at minimum level.

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II. Method

A. 2D- FDTD Method

In two-dimensional problems, there is no variation with respect to third coordinate in either the problem geometry or excitation. Here, it is assumed z-direction, which means that all partial derivatives of the fields with respect to z axis equal to zero, and that the structure being modeled extends to infinity in the z-direction with no change in its geometry.

When three-dimension FDTD formula is reduced to two-dimensions, there are two modes, namely transverse electric (TE) and transverse magnetic (TM) modes. TE mode only includes electric field (E field) components transverse to the geometry axis (i.e., the z-axis). TM mode only includes magnetic field components transverse to the *z*-axis. Two-dimensional TM mode is

$$\frac{\partial H_x}{\partial t} = \frac{1}{\mu}\left(-\frac{\partial E_z}{\partial y} - \rho' H_x\right) \quad (1a)$$

$$\frac{\partial H_y}{\partial t} = \frac{1}{\mu}\left(\frac{\partial E_z}{\partial x} - \rho' H_y\right) \quad (1b)$$

$$\frac{\partial E_z}{\partial t} = \frac{1}{\varepsilon}\left(\frac{\partial H_y}{\partial x} - \frac{\partial H_x}{\partial y} - \sigma E_z\right) \quad (1c)$$

Two-dimensional TE mode is

$$\frac{\partial E_x}{\partial t} = \frac{1}{\varepsilon}\left(\frac{\partial H_z}{\partial y} - \sigma E_x\right) \tag{2a}$$

$$\frac{\partial E_y}{\partial t} = \frac{1}{\varepsilon}\left(\frac{\partial H_z}{\partial y} - \sigma E_y\right) \tag{2b}$$

$$\frac{\partial H_z}{\partial t} = \frac{1}{\mu}\left(\frac{\partial E_x}{\partial y} - \frac{\partial E_y}{\partial x} - \rho' H_z\right) \tag{2c}$$

TM and TE modes are decoupled, namely, they contain no common field vector components. In fact, these modes are completely independent for structures comprised of isotropic materials. That is, the modes can exist simultaneously with no mutual interactions. Problems having both TM and TE excitation can be solved by a superposition of these two separate problems [6].

When two-dimensional TM mode is discretized FDTD formulas are

$$H_{x,i,j+1/2}^{n+1/2} = D_a \cdot H_{x,i,j+1/2}^{n-1/2} + D_b\left(E_{z,i,j}^{n} - E_{z,i,j+1}^{n}\right) \tag{3a}$$

$$H_{y,i+1/2,j}^{n+1/2} = D_a \cdot H_{y,i+1/2,j}^{n-1/2} + D_b\left(E_{z,i+1,j}^{n} - E_{z,i,j}^{n}\right) \tag{3b}$$

$$E_{z,i,j}^{n+1} = C_a \cdot E_{z,i,j}^{n} + C_b \cdot (H_{y,i+1/2,j}^{n+1/2} - H_{y,i-1/2,j}^{n+1/2} + H_{x,i,j-1/2}^{n+1/2} - H_{z,i,j+1/2}^{n+1/2}) \tag{3c}$$

$$C_a = \frac{(2 \cdot \varepsilon - \sigma \cdot \Delta t)}{(2 \cdot \varepsilon + \sigma \cdot \Delta t)} \tag{4a}$$

$$C_b = \frac{2 \cdot \Delta t}{\Delta x \cdot (2 \cdot \varepsilon + \sigma \cdot \Delta t)} \tag{4b}$$

$$D_a = \frac{(2 \cdot \mu - \sigma * \cdot \Delta t)}{(2 \cdot \mu + \sigma * \cdot \Delta t)} \tag{4c}$$

$$D_b = \frac{2 \cdot \Delta t}{\Delta x \cdot (2 \cdot \mu + \sigma * \cdot \Delta t)} \tag{4d}$$

where Δt is time increment, Δx is space increment in the x-direction and is assumed equal to Δy.

In a programming language, there is no location like *n*+1/2. So these subscripts can be rounded to upper integer value [7].

$$H_{x,i,j+1}^{n+1} = D_a \cdot H_{x,i,j+1}^{n} + D_b\left(E_{z,i,j}^{n} - E_{z,i,j+1}^{n}\right) \tag{5a}$$

$$H_{y,i+1,j}^{n+1} = D_a \cdot H_{y,i+1,j}^{n} + D_b\left(E_{z,i+1,j}^{n} - E_{z,i,j}^{n}\right) \tag{5b}$$

$$E_{z,i,j}^{n+1} = C_a \cdot E_{z,i,j}^{n} + C_b \cdot (H_{y,i+1,j}^{n+1} - H_{y,i,j}^{n+1} + H_{x,i,j}^{n+1} - H_{x,i,j+1}^{n+1}) \tag{5c}$$

B. Courant Stability Criterion

The parameters of FDTD algorithm (Δx, Δy and Δt) must be determined with the Courant stability criterion as follows for 2D [8]

$$\Delta t \le 1 \Big/ c \cdot \sqrt{\frac{1}{\Delta x^2} + \frac{1}{\Delta y^2}} \tag{6}$$

where c is the light velocity. Δx and Δy should be less than or equal to $\lambda / 20$ [6].

C. Absorbing Boundary Conditions (ABCs)

Spurious wave reflections occur at the boundaries of computational domain due to nature of FDTD code. Virtual absorbing boundaries must be used to prevent the reflections there. Many ABCs have been developed over the past several decades. Mur's ABC is one of the most basic ABCs. There are two Mur's ABCs to estimate the fields on the boundary, which are first-order and second-order accurate. FDTD simulations have been carried out in 2 dimensions with first order Mur's absorbing boundary conditions, therefore, they did not require a super computer system to perform. Considering the E_z component located at $x = i\Delta x$, $y = j\Delta y$ for two-dimensional case, the first order Mur estimate of E_z field component on the boundary is [9]

$$E_{i,j}^{n+1} = E_{i-1,j}^{n} + \frac{c\Delta t - \Delta x}{c\Delta t + \Delta x}\left(E_{i-1,j}^{n+1} - E_{i,j}^{n}\right) \tag{7}$$

III. Developed Programs

A program was developed in the Matlab programming language to examine the propagation of mobile phone radiation [10]. Representation of the area analyzed in the program is shown in Fig. 1. Flow chart of the program is shown in Fig. 2. As shown in Fig. 2 firstly required parameters of the program is entered by the user; and the area of analysis is divided into cells, and matrices are created for the electric and magnetic field components (*E*, *H*) calculated at each time step and each cell. Then mathematical function of electric field emitted by mobile phone antenna is entered. Absorbing boundary conditions are applied to eliminate artificial reflections and loops are carried out to calculate the electric and magnetic field values by stepping in the position and the time in the part that can be called FDTD Cycle. The maximum electric field value is recorded at test point (T) for 1g or 10g SAR. SAR values are calculated by using the following formula for each cell [11], and then 1g or 10g averaged SAR were obtained by taking the average of them.

$$SAR = \frac{\sigma \cdot |E_T|^2}{2 \cdot \rho} \quad W/kg \tag{8}$$

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Here, σ is average conductivity of the head, ρ is average mass density. E_T is the maximum electric field calculated for test point.

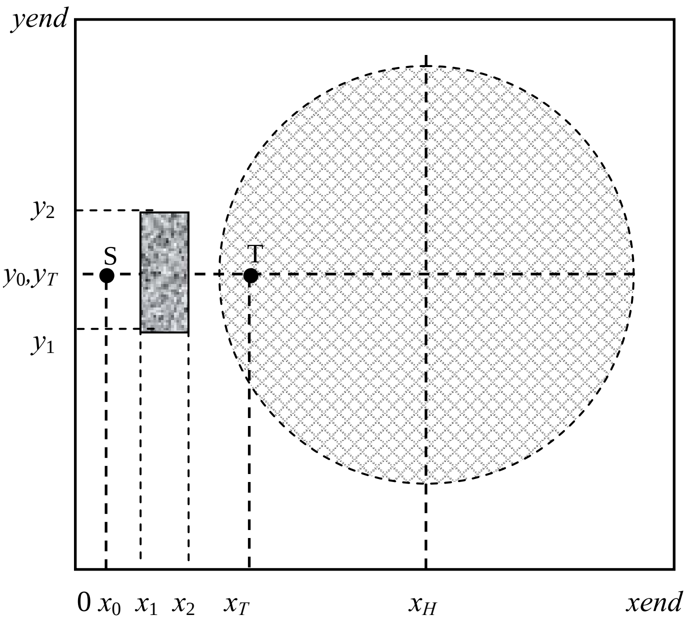

Figure 1. Representation of the 2D simulation area

A graphical interface has been designed for the developed program. This interface is shown in Fig. 3. All required data are entered here, and then the program is executed with the START button.

In part of media characteristics, ε_r, μ_r, σ and σ^* parameters are entered as the electrical properties of the environment. In part of source features, frequency (MHz), mathematical function and location information of source are entered. In part of simulation parameters, size (xend, yend) in terms of space increments of the area that will be analyzed, the calculation time (tend) in terms of time increment, time increment (in ps) and the space increment (in mm) are entered. In part of Shield features ε_r, μ_r, σ and σ^* parameters are entered as electrical properties of the shield, and $x1$, $x2$, $y1$, $y2$ parameters are entered as its location and size. In part of test point, the coordinates of point to calculate electric field and number of cells are entered. In part of head location, the center coordinates of head which is approximately assumed as circular are entered.

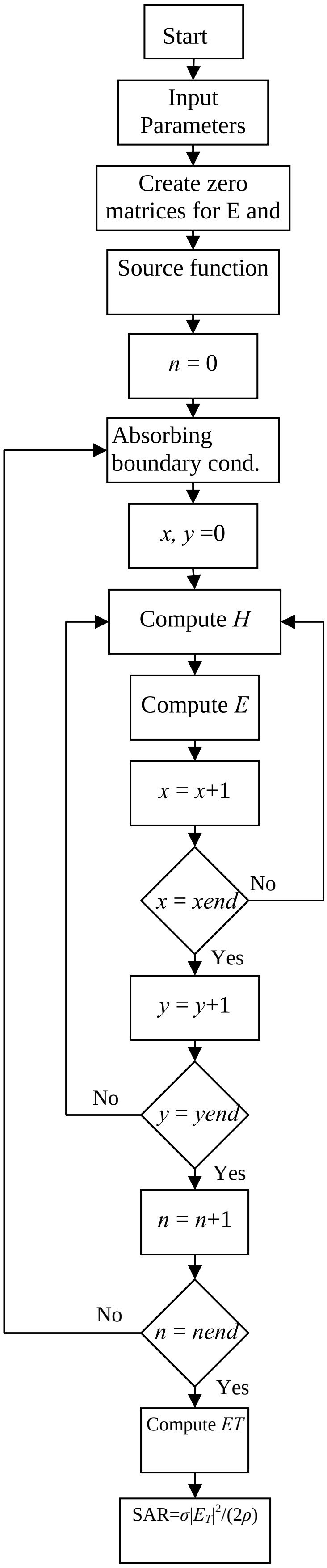

Figure 2. Flow diagram for developed program

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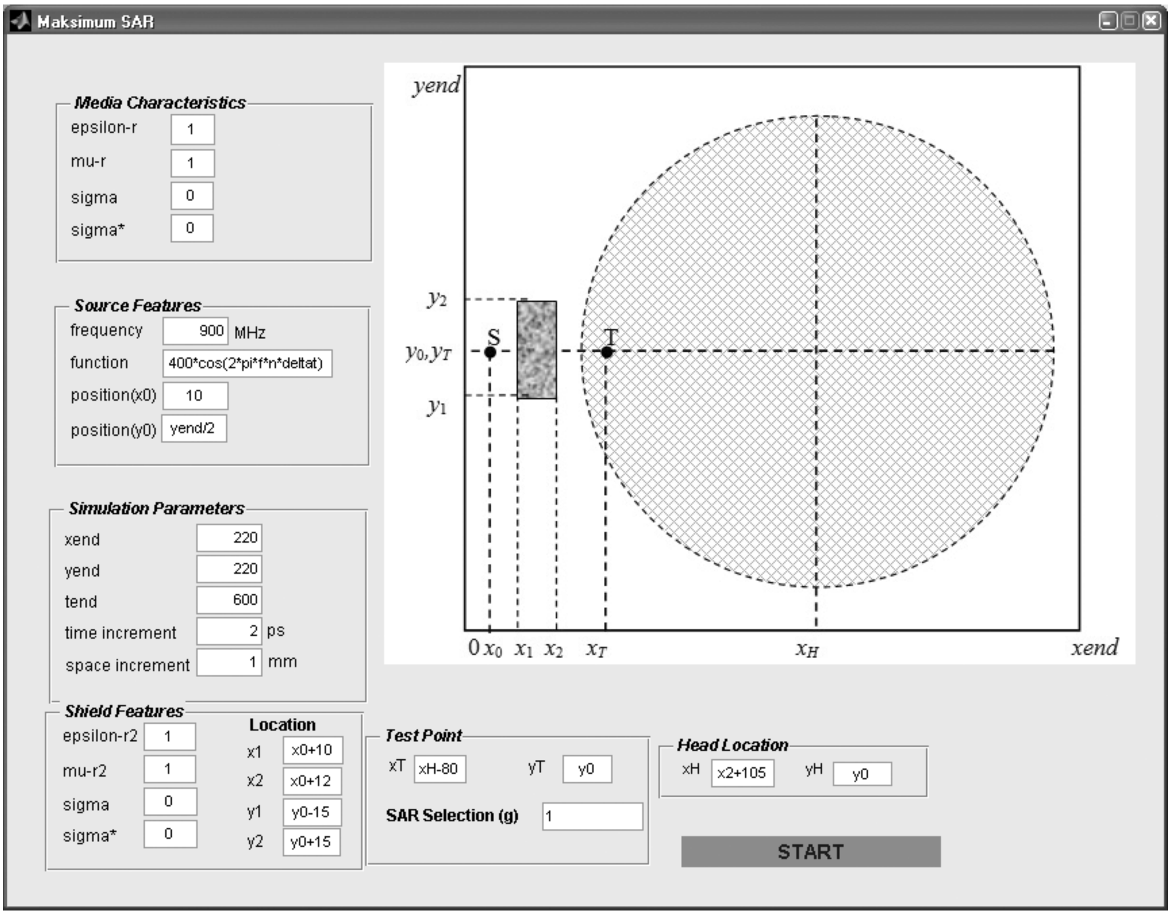

Figure 3. Graphical interface of the developed program

IV. Input Parameters

Time increment and space increment as FDTD parameters of simulation were 2ps and 1mm, respectively. SAR is calculated at 8 cells for 1g in the vicinity of test point, 80 cells for 10g SAR. Simulations were performed for unshielded case by entering the electrical properties of free space in shield features section in the developed program's graphical user interface and by entering the electrical properties of copper (σ = 5.8x10^7 S/m, 30x2mm sized) for shielded case, separately. Average electrical conductivity of head in which SAR values are calculated has been assumed to be 0.97 S/m, the average mass density 1000 kg/m^3, relative permittivity 41.5, and the diameter 180 mm at 900 MHz [12], [13].

V. Simulation Results

1g and 10g averaged SAR values have been calculated for both of cases as given in Table 1. Shielding effectiveness (SE) was calculated by using the obtained values from simulation results in the following formula.

$$SE = 20 \cdot log \frac{S1}{S2} \text{ (dB)} \quad (9)$$

Here, $S1$ is the SAR value in shielded case, $S2$ is one in unshielded case.

Table 1. Obtained SAR values from simulation results and shielding effectiveness values

	SAR (W/kg)Without shield	**SAR (W/kg)With copper shield**	**SE (dB)**
1g	0.7079	0.0061	-41.3
10g	0.5958	0.0060	-39.9

As shown in Table 1, SAR value decreased to 0.0061 W/kg from 0.7079 W/kg for 1g averaged case and to 0.0060 W/kg from 0.5958 W/kg for 10g averaged case under the influence of copper shield.

VI. Conclusion

In this study, attenuation of radiation towards user from mobile phone with copper shield at 900 MHz frequency has been investigated by calculating the SAR values in some simulations. 1g and 10g averaged SAR values were separately computed. As a result of the simulation shielding effectiveness were calculated by using estimated SAR values for shielded and unshielded conditions.

As a result of simulations, it was found that the SAR values exposing mobile phone user were reduced about 40 dB by using copper shield.

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