EM EXPOSURE STUDY OF A HUMAN INSIDE THE CAR

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Abstract

The goal of the proposed research is to investigate the influence of mobile phone's EM Radiation on a human, when it is located inside the car and study possible resonant fields in cars. We have investigated several cases when a human with a cellphone is located inside a car and also the case when the EM source is the base station antenna located outside, at 450 MHz, 900 MHz and 1800 MHz frequencies. The problems are solved using the Method of Auxiliary Sources (MAS). The numerical results showed the presence of resonance phenomena and high reactive field (standing waves) in several scenarios, that causes higher SAR in human tissues and could be dangerous for a human.

1. INTRODUCTION

Nowdays it's especialy important and actual to investigate the impacts of electromagnetic fileds (EMF) emitted from the cellphones and other wireless communication devices on human. The interaction between the EMFs and the biological object depends on the characteristics of the emitting source, as well as the ability to absorb and accumulation energy by biological organisms. Many publications show that absorption of radiated energy (SAR) depends on mobile phones and antenna types [1, 2], its positions, and radiated power from the mobile phones [3]. The radiation nature and EM fields behavior depends on complex human body geometry [4], user hand and fingers positions [2, 5], other subjects' existence around the user, etc. It's also important to consider where the user is located, in an enclosed or semi-enclosed space (room, car, etc.). But it's impossible to thoroughly quantitatively consider all these details.

In our previous works [6, 7] we have investigated the cellphone's antenna and base station's radiation influence on the user located inside the room with a window. The studies were conducted by the Method of Auxiliary Sources (MAS), which was also used to simulate room walls with different transparency. The results showed the presence of high reactive fields in the room with less walls transparency [7].

In this paper our goal is to investigate mobile phones antenna EM exposure influence on a human, when person is located inside the car and study possible resonant fields in cars at 900 MHz and 1800 MHz radiation frequencies. The motivation of this research is that we often use mobile phones and other handsets in a car (e.g. walkie-talkies are used in police cars). As it is known, cars are made using metal and other conductive materials, which are less transparent to EM waves. At some frequencies in the mobile frequency range, this closed metal structure behaves as a resonator and amplifies the antenna radiated near field, which becomes dangerous for the user. Besides, the novelty in the proposed research is the ground effect consideration under the car, as a reflective surface. It is also important to study SAR distributions inside the human body and investigate the fields' behavior in the near and far zone.

There are some publications [8-9] similar to the stated problem solved by different numerical methods, but we suppose that, the EMF exposure influence on a human inside the car is not studied completely yet.

2. MATHEMATICAL APPROACH AND METHODOLOGY

We consider the system model which consists of the car and human inside it. The system is irradiated by the known EM wave, which is located inside the car as a mobile phone antenna. Our goal is to find the EMF distribution inside and outside the car and also, inside a human body and also to investigate the earth surface influence on the resonant field formation inside the car. In the considered model (Figure 1) the car represents the perfectly conductor surface S. On these surface there are open parts like windows σ_w, $w = 1, 2, \ldots$ - number of glasses. As a human model we use the homogenous dielectric model of a human shape "Mummy" with averaged permittivity and losses [6], which is bounded with the closed surface S_0.

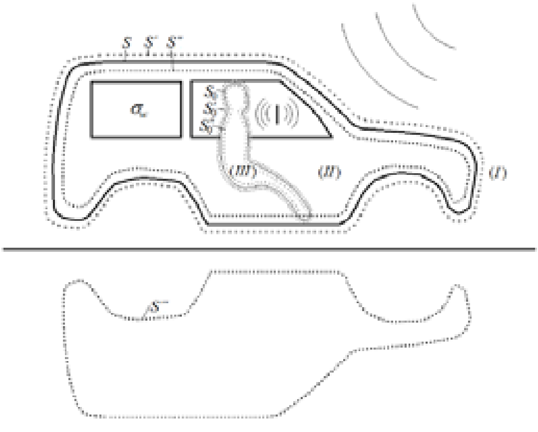


Figure 1. MAS model of cavity with using auxiliary surfaces

The irradiated fields of the inner source $\vec{E}^1_{inc}, \vec{H}^1_{inc}$ (first case) and the field of the outer source $\vec{E}^2_{inc}, \vec{H}^2_{inc}$ (second case) are initially given. We have to determine the field in three areas: (I) outside the car, (II) inside car, (III) inside human (Figure 1). We denote these fields correspondingly $\vec{E}_{(I)}, \vec{H}_{(I)}$, $\vec{E}_{(II)}, \vec{H}_{(II)}$, $\vec{E}_{(III)}, \vec{H}_{(III)}$. The stated problem is solved numerically, using the Method of Auxiliary Sources (MAS).

For this reason we construct two couples of auxiliary surfaces: S_0', S_0'' - outside and inside human, and S', S'' – outside and inside car, where the auxiliary sources are distributed. As the auxiliary sources two mutual perpendicularly oriented combined dipoles (Huygens source) [10, 11] with unknown amplitudes are used. The electric and magnetic field of the combined dipole we denote as:

$$\begin{aligned} &\vec{G}_E \to \vec{G}_E\left(\vec{r}, \vec{r}_0, \vec{p}_e, \vec{p}_h, \varepsilon, \mu\right), \\ &\vec{G}_H \to \vec{G}_H\left(\vec{r}, \vec{r}_0, \vec{p}_e, \vec{p}_h, \varepsilon, \mu\right), \end{aligned} \quad (1)$$

Where $\vec{r}$ and $\vec{r}_0$ are the observation point and dipole location point radius-vectors, $\vec{p}_e$ and $\vec{p}_h$ – are the unit vectors of the electric and magnetic dipole polarization, ε and μ-are media parameters. In order to describe the scattered field of any polarization, in each point of the auxiliary surface we consider two such dipoles, distributed in the tangent plane and rotated by 90^0 to each other. Respectively, for electric and magnetic field of the auxiliary source we have:

$$A_0\vec{G}_E + B_0\vec{G}_E', \quad A_0\vec{G}_H + B_0\vec{G}_H' \quad (2)$$

Where: $\vec{G}_E' \to \vec{G}_E\left(\vec{r}, \vec{r}_0, \vec{p}_e', \vec{p}_h', \varepsilon, \mu\right)$, $\vec{p}_e' = \vec{p}_h$, $\vec{G}_H' \to \vec{G}_H\left(\vec{r}, \vec{r}_0, \vec{p}_e', \vec{p}_h', \varepsilon, \mu\right)$, $\vec{p}_h' = -\vec{p}_e$, A_0 and B_0 are unknown complex amplitudes, which can be determined by satisfaction of the the corresponding boundary conditions.

The field in the first (I) area is the sum of the incident field $\vec{E}^1_{inc}, \vec{H}^1_{inc}$ and the field described by the auxiliary sources on the surface S''. The field in the second (II) area is the sum of the incident field $\vec{E}^2_{inc}, \vec{H}^2_{inc}$ and the fields described by the sources located on the surface S' and S_0''. In the third (III) area the field is described by the sources on the surface S_0' (Figure 1). Therefore:

$$\vec{E}_{(I)}\left(\vec{r}\right) = \vec{E}^1_{inc}\left(\vec{r}\right) + \sum_{n=1}^{N}\left[A_n\vec{G}_E + B_n\vec{G}_E'\right]_{\vec{r}_n \in S''} \quad (3)$$

$$\begin{aligned} \vec{E}_{(II)}\left(\vec{r}\right) = \vec{E}^2_{inc}\left(\vec{r}\right) + \sum_{n=1}^{N}\left[C_n\vec{G}_E + D_n\vec{G}_E'\right]_{\vec{r}_n \in S'} + \\ + \sum_{m=1}^{N_0}\left[E_m\vec{G}_E + F_m\vec{G}_E'\right]_{\vec{r}_m \in S_0''} \end{aligned} \quad (4)$$

$$\vec{E}_{(III)}\left(\vec{r}\right) = \sum_{m=1}^{N_0}\left[K_m\vec{G}_E + L_m\vec{G}_E'\right]_{\vec{r}_m \in S_0'} \quad (5)$$

$$\vec{H}_{(I)}\left(\vec{r}\right) = \vec{H}^1_{inc}\left(\vec{r}\right) + \sum_{n=1}^{N}\left[A_n\vec{G}_H + B_n\vec{G}_H'\right]_{\vec{r}_n \in S''} \quad (6)$$

$$\begin{aligned} \vec{H}_{(II)}\left(\vec{r}\right) = \vec{H}^2_{inc}\left(\vec{r}\right) + \sum_{n=1}^{N}\left[C_n\vec{G}_H + D_n\vec{G}_H'\right]_{\vec{r}_n \in S'} + \\ + \sum_{m=1}^{N_0}\left[E_m\vec{G}_H + F_m\vec{G}_H'\right]_{\vec{r}_m \in S_0''} \end{aligned} \quad (7)$$

$$\vec{H}_{(III)}\left(\vec{r}\right) = \sum_{m=1}^{N_0}\left[K_m\vec{G}_H + L_m\vec{G}_H\right]_{\vec{r}_m \in S_0'} \quad (8)$$

In the given expression there are unknown complex amplitudes A_n, B_n, C_n, D_n, E_m, F_m, K_m L_m of the auxiliary sources, the total number of which is $4 \cdot \left(N + N_0\right)$. These amplitudes can be determined from the boundary conditions. On the surface S as on the conductor, the tangent components of the complete fields $\vec{E}_{(I)}$, $\vec{E}_{(II)}$ must be zero; On the windows surfaces σ_w and human model surface, as on the dielectric, the tangent components of the fields $\vec{E}_{(I)}, \vec{E}_{(II)}, \vec{H}_{(I)}, \vec{H}_{(II)}$ and $\vec{E}_{(II)}, \vec{E}_{(III)}$, $\vec{H}_{(II)}, \vec{H}_{(III)}$ must be continuous. As a result, we get the system of the linear algebraic equations to the unknown amplitudes. After solution of this system using the computer numerically, the unknown fields are determined in all given areas.

As it was mentioned above, the big interest is to investigate the ground surface influence on the fields formation. We suppose that the ground surface is perfect planar conductor. This gives ability to use the method of the mirror image in order to describe the reflected field. The consideration of the reflected field adds the additional terms in the expressions (3) and (6) for the field in the first area. As for the fields in the second and third areas the reflected field changes only the amplitudes of the auxiliary sources.

According to the MAS, towards ground there is constructed the mirror image S''' of the surface S'' (Figure 1). The amplitudes of the auxiliary sources on the surface S''' differs from the corresponding sources on the surface S'' only by sign as it is in case of the mirror image. In the other words the consideration of the ground surface doesn't change the number of the unknown coefficients. The field in the first area has the form:

$$\vec{E}_{(I)}(\vec{r}) = \vec{E}^{1}_{inc}(\vec{r}) + \sum_{n=1}^{N} \left[A_n \vec{G}_E + B_n \vec{G}'_E \right]_{\vec{r}_n \in S''} + \sum_{n=1}^{N} \left[(-A_n) \vec{G}^{*}_E + (-B_n) \vec{G}'^{*}_E \right]_{\vec{r}_n \in S'''} \quad (9)$$

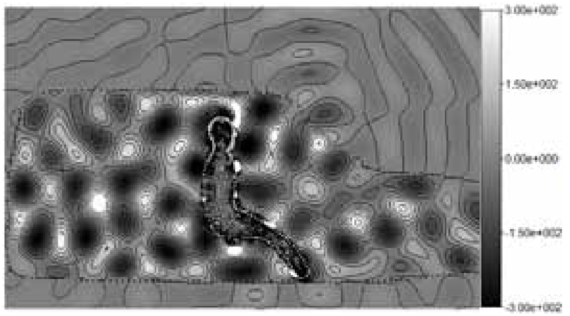
$$\vec{H}_{(I)}(\vec{r}) = \vec{H}^{1}_{inc}(\vec{r}) + \sum_{n=1}^{N} \left[A_n \vec{G}_E + B_n \vec{G}'_E \right]_{\vec{r}_n \in S''} + \sum_{n=1}^{N} \left[(-A_n) \vec{G}^{*}_E + (-B_n) \vec{G}'^{*}_E \right]_{\vec{r}_n \in S'''} \quad (10)$$

The unknown amplitudes are again determined from the boundary conditions.

3. RESULTS OF NUMERICAL SIMULATIONS AND DISCUSSIONS

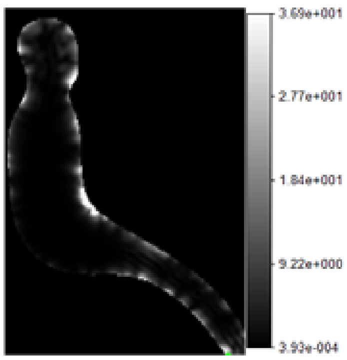
Based on above proposed methodology (MAS), we have created program package and investigated several exposure scenarios. Calculations were carried out at 900 and 1800 MHz radiation frequencies. EM source is placed at 2.5 cm distance from the human head. The car has following dimensions (LWH): 4.10 x 1.76 x 1.57 [m].

For all results near and far field values are given in the relative units, whereas point SAR values are provided in W/Kg and normalized to 1 W input power.



a)

b)



c)

Figure 2. Near field distribution in XOZ plane inside the car (a), far field pattern (b) and point SAR distribution (W/Kg) for the human body (c) at 900 MHz.

On Figures 2 (a, b, c) near field distribution inside the car in XOZ section and far field pattern and point SAR distribution for the human body at 900 MHz frequency are presented respectively. In this case point SAR peak value is 36.9 W/Kg. The wavelength is smaller than car window size and radiated energy penetrates inside the car though the side windows mainly. Standing waves are observed in the back part of car. The bottom of pattern shape is flat, which is caused by the field reflection and propagation over the ground surface under the car.

We have investigated car’s resonant properties and generate resonant characteristic near to the 900 MHz frequency. Figure 3 shows the detailed frequency characteristic on which we see the sharp, discriminated resonance frequency 899.9 MHz.

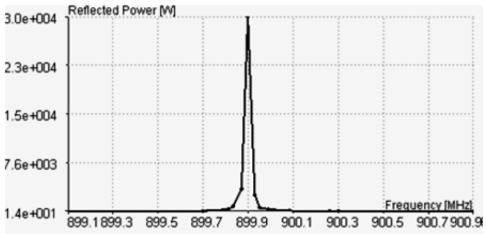
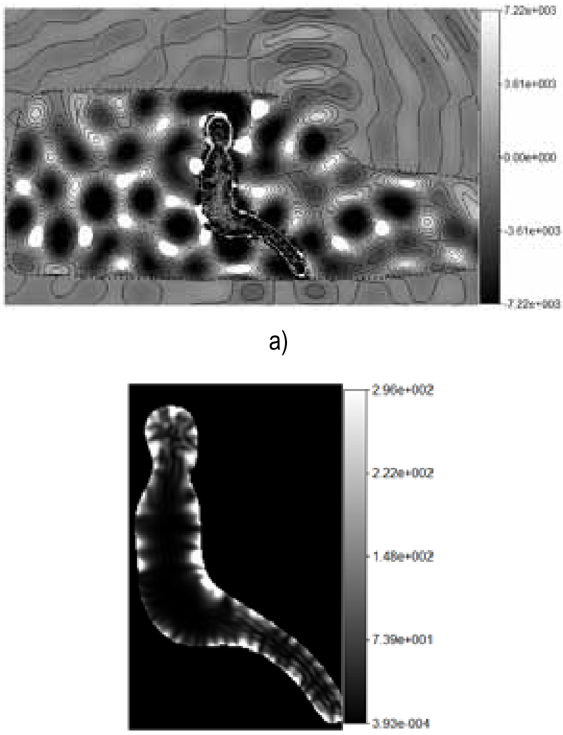


Figure 3. Frequency characteristic for the car with human model inside, near to 900 MHz

Figure 4 shows near field inside the car (a) and point SAR distribution for the human body (b) at 899.9 MHz resonant frequency. As it seen from the obtained result inside the car is created high reactive field and the point SAR peak value is about ten times higher than it was for the 900 MHz frequency.



a)

b)

Figure 4. Near filed distribution inside the car (a) and point SAR (b) distribution for the human body at 899.9 MHz resonant frequency

We have also studied the near field distribution inside the car at 1800 MHz (Figure 5). Because of the high losses at this frequency the depth of the field penetration in the human model is smaller than for the lower frequencies and EM field absorption occurs mostly in the skin layer.

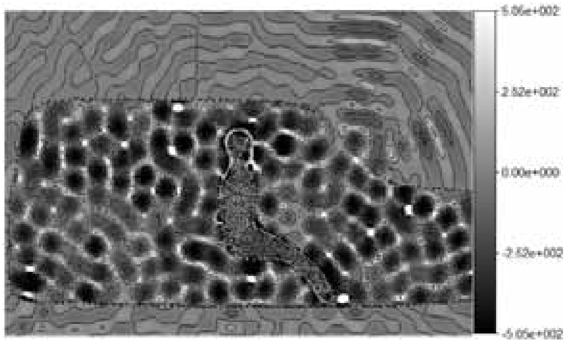


Figure 5. Near field distribution in the car at 1800 MHz frequency (source is base station antenna).

On Figure 6 are presented the SAR values inside the human body, when it is located in free space and in the car, at 450, 900 and 1800 MHz frequencies. We see that in the car these values for the human body is almost 4 times higher than in free space, which can be dangerous for the human.

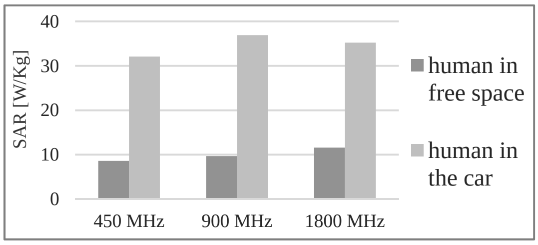


Figure 6. Point SAR values for the human body, when EM source is near the head.

We have also considered the case, when the ground effect under the car isn’t taking into account. In this case the field values inside the car is lower (Figure 7) than in case when we consider this effect (Figure 2a).

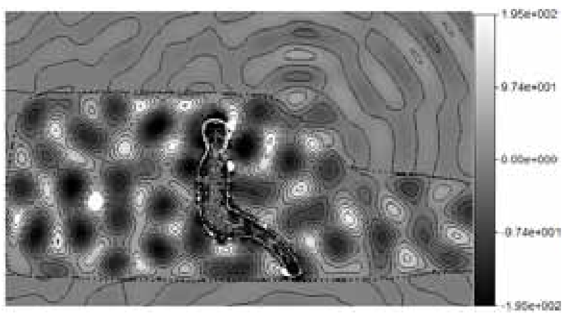


Figure 7. Near field distribution in XOZ plane inside the car without considering ground effect at 900 MHz

For all obtained above results calculation error was less than 20%.

4. CONCLUSION

The mobile phone's EM exposure problem for a human model located in the car is studied using the Method of Auxiliary Sources. This method was also used to simulate ground reflective surface. The obtained results, conducted with the MAS based program package, showed the presence of resonance and reactive fields inside the car, that causes high SAR in human tissues. It was shown that these SAR values is much higher than in case, when human is in free media. The reason of this is that at the considered frequencies car's metallic surface acts as the resonator. So it isn't desirable speak on phones for a long time inside the car, that can be hazardous for the cellphone users.

5. ACKNOWLEDGMENT

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