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Study on Evaluation of Induced Current within a Human Body by Electromagnetic Field of a Mobile Phone

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Abstract: Electromagnetic fields having various frequency are around us and the necessity of the study on EMC problems or on the effect of electromagnetic field on a human being has been more and more increasing. Authors have already contributed those problem by electromagnetic field of extremely low frequency like 50Hz.
However,this paper deals with the electromagnetic field and the evaluation of its induced current within a human body by a mobile phone as a problem of high frequency like 1GHz and aims mainly at the study of evaluation method to those high frequency.

Simulations by recent 3D Finite Element Method are useful and applied both for elctromagnetic and heat transfer problems.

Key Words: Mobile phone;Electromagnetic field;Induced current;Specific Absorption Rate

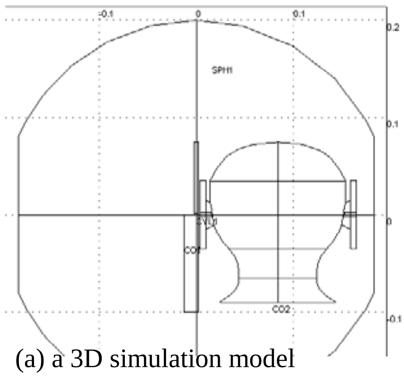
1 INTRODUCTION

The authors have contributed the effect of electromagnetic fields by a transmission line and a hair dryer of 50Hz on a human being up to the present [1][2] .

The electromagnetic field of a mobile phone having high frequency like 1GHz is said to have different effect on a human being compared with that of extremely low frequency and to have thermal action.

The effect of electromagnetic field of 100MHz to 10GHz on a human body is said to be mainly that of temperature rise of a body and ICNIRP guidelines[3]specifies the magnitude of SAR(Specific Absorption Rate:W/kg) both to occupational and public exposures. However, how to get SAR is left entirely to each problem.

Some literatures[4][5] deal with the problem in the past. But there are many parameters to get SAR and temperature rise of a human body.



(a) a 3D simulation model

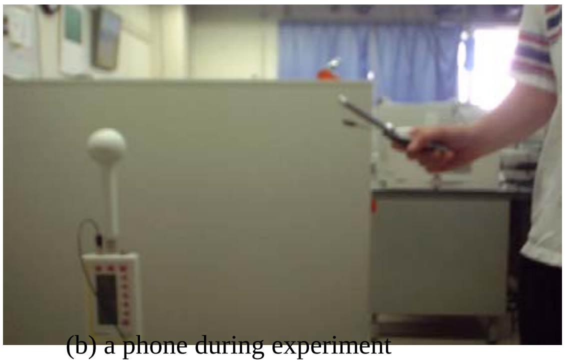

(b) a phone during experiment

Fig.1 A simulation model and an outline view.

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remarkably advanced and these problems can be solved comparatively easily with accuracy by a normal personal computer. The method and parametric study are described in the following.

2 MODELS AND CONSTANTS

Figure 1 shows the model used in this study and the test site. The model is composed of a mobile phone having a metal box and an antenna in center, a head of human being coming close to the phone and the surrounding sphere air space of diameter 0.8m.

And typical constants used are shown in Table 1.
As for a phone,frequency is set to be 1GHz and standard antenna current to be 30mA in peak although the magnitude of its current is changed parametrically.
As for a human body, conductivity is assumed to be 1S/m as typical value to 1GHz and the coefficient B of blood flow in eq.(4) to be 2700W/m$^3 \bullet$K. Main effect on a human body is said to be heat action in these frequency.

Table 1 List of typical constants

mark	content	value
f0	frequency(Hz)	10e8
μ_s	relative permeability	1
sigm	metal conductivity(S/m)	5e7
sigh	human conductivity(S/m)	1
I0	Standard antenna current(A)	0.03
r0	antenna radius(m)	0.002
e0r	relative permittivity of air	1
emr	relative permittivity of a metal	1
ehr	human relative permittivity	1
rho_h	human specific gravity (kg/m^3)	1000
C_h	Human specific heat capacity (J/kg $\bullet$ K)	3600
B	Coefficient of blood flow(J/m$^3 \bullet$ s $\bullet$ K)	2700
hh	heat transfer coefficient(J/m$^2 \bullet$ s $\bullet$ K)	10
l	antenna length(m)	0.074
kk	coefficient for antenna current distribution(m^{-1})	20.94
ka_h	human thermal conductivity (J/m $\bullet$ s $\bullet$ K)	0.5
Tout	external temperature(K)	310

3 THEORY

Electric field E is derived into eq.(3) in time harmonics from Maxwell equations (1) and (2) in case of the existance of external current density J^e of antenna.

$$\nabla \times H = \sigma E + \varepsilon \frac{\partial E}{\partial t} + J^e ---(1)$$

$$\nabla \times E = -\mu \frac{\partial H}{\partial t} --------(2)$$

Having time harmonic form of $Ee^{j\omega t}$ *and* $He^{j\omega t}$,

$$\nabla \times (-\mu_s^{-1} \nabla E) + \mu_0 \omega(\varepsilon\omega - j\sigma)E = j\omega\mu_0 J^e ----(3)$$

Here, $\mu = \mu_s \mu_0$

H : *magneticfield*, σ : *conductivity*, ε : *permittivity*, μ : *permeability*, μ_s : *relative permeability*, μ_0 : *vacuum permeability*; ω : *angular velocity*, σ : *conductivity*.

And regarding heat transfer equation of a human body, the following formula is applicable.

$$rho\_h * C\_h \frac{\partial T}{\partial t} - \nabla \bullet (ka\_h * \nabla T) = \frac{\sigma E^2}{2}$$

$$- B(T - T0) ------------(4)$$

Here, T : *body temperature*(K), $T0$: *normal body temperature*$(310K)$.

4 RESULTS

4.1Electromagnetic field and etc.

Firstly antenna current was measured by high frequency CT and shown in Fig.2 on a recent mobile phone.

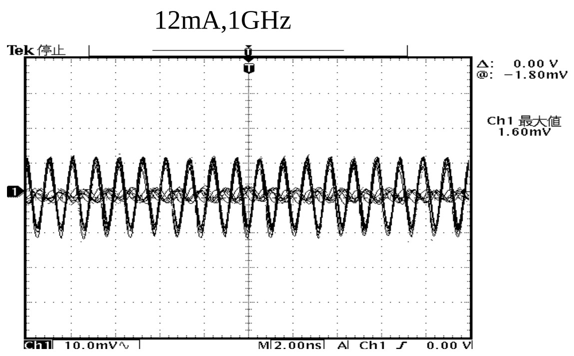

Fig.2 An example of the measurement of A antenna current by high frequency CT.

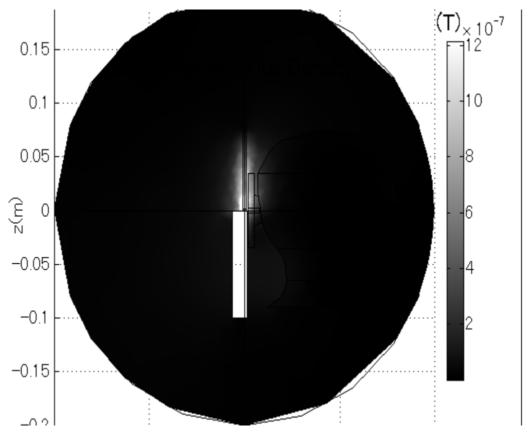

Fig.3 Magnetic flux density distribution by slice plot.

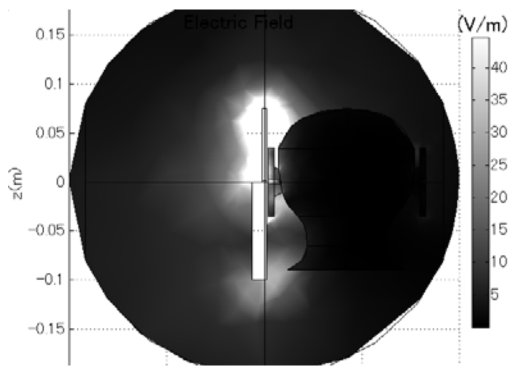

Fig.4 Electric field distribution by slice plot.

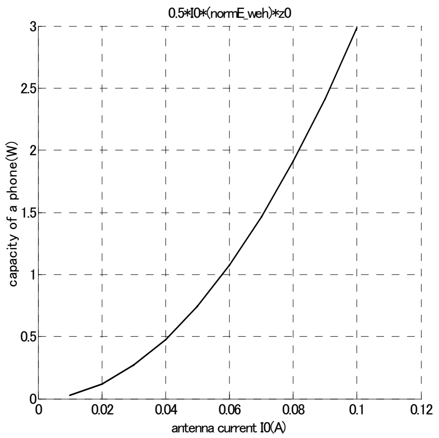

Fig.5 Relation between antenna current And rating watt of a phone in the model.

The frequency is 1GHz and the current peak 12mA in this case. And the following analysis was conducted under the condition where frequency is 1GHz and standard current peak 30mA with margin.

Fig.3 and 4 show the distribution of respectively magnetic flux density and electric field by the color expression of slice plot. Color bar is set to show quantities inside air and a human body.

The relation between the rating watt in the simulation model and antenna current is illustrated in Fig.5 where 1 watt coresponds to 60mA antenna current.

Fig 6 shows the radial distribution on magnetic flux density of the antenna and also it rapidly decreases from 1.8 μT at the proximity of the antenna to nearly zero lebel at the 20cm far.

Fig.7 shows the radial distribution on electric field of the antenna and it rapidly decreases from

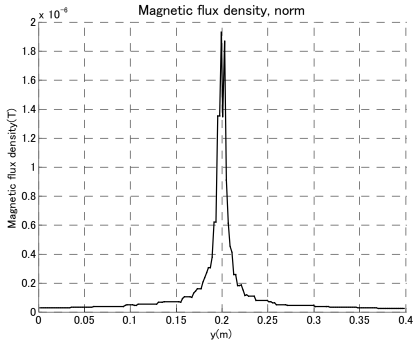

Fig.6 Magnetic flux distribution around the antenna(with no human body).

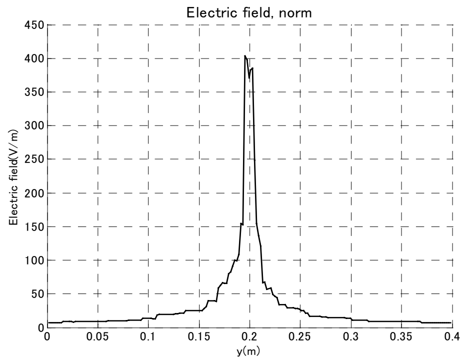

Fig.7 Electric field distributoion around the antenna(with no human body).

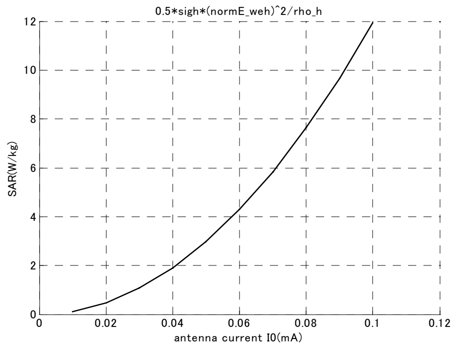

Fig.8 Antenna current and SAR.

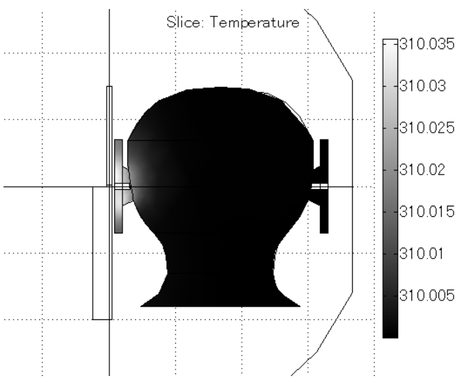

Fig.9 Temperature rise by slice plot.

400V/m at the proximity of the antenna to nearly zero lebel at the 20cm far.

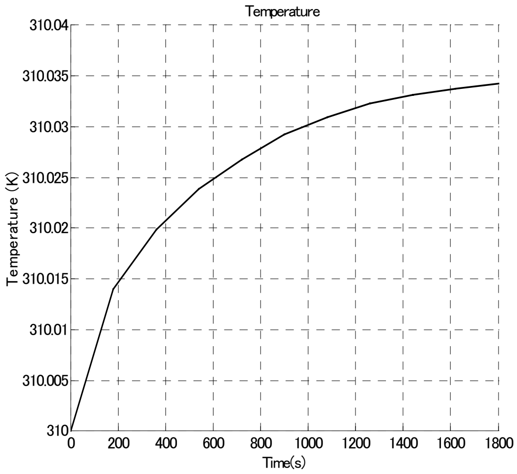

Fig.10 Time of temperature rising.

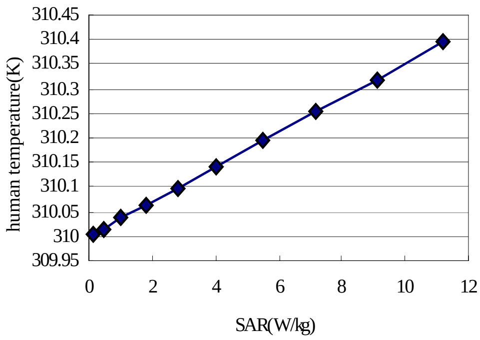

Fig.11 SAR and temperature rise.

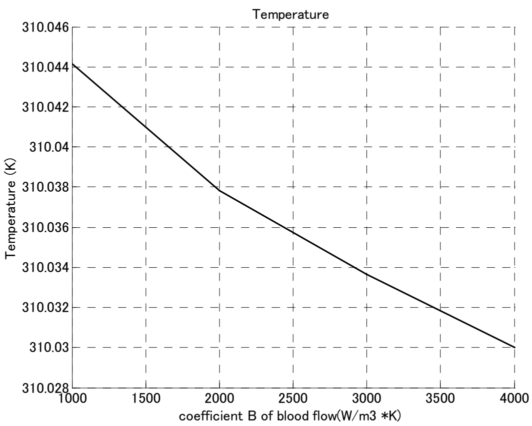

Fig.12 Coefficient B of blood flow and Temperature rise.

4.2 SAR

Fig.8 shows the relation between antenna peak current and SAR(Specific Absorption Rate:W/kg) of a human body. SAR can be expressed as $\frac{1}{2} sigh \cdot E^2$ (E:electric field inside a human body).

SAR is approximatelely proportional to the square of antenna current ,i.e. to the power of a mobile phone.

30, 40 and 90 mA in peak give respectively SAR 1,2 and 10(W/kg).

And the condition of 30mA corresponding to SAR 1 is adopted as standard value in this study.

SAR 2 and 10 corespond to the restriction levels respectively to general public exposure and occupational exposure at head and trunk to these frequency in ICNIRP guidelines[3].

4.3 Temperature rise

The temperature rise under the standard condition specified in Table 1 is shown in Fig.9. Maximum rise of temperature is 0.035K at the ear.

The time is required after the application of electromagnetic field for the temperature of a human body to rise the steady state level.

Therefore, time domain study has been conducted. Fig.10 is the result and it shows that the temperature rises exponentially and approximately 30 minutes is needed to reach steady state of 0.035K.

Fig.11 is the case where the temperature of a human body was got by parametric study of the magnituge of SAR by changing antenna current.

Restriction levels of 2 and 10 (W/kg) on SAR in ICNIRP guidelines correspond to respectively approximately 0.1 and 0.35K in temperature rise in this study.

Coefficient B of blood flow is very influential in temperature rise. It depends on tissues . Therefore, parametric study on the values of B has conducted at the range of 1000 to 4000(W/m^3*K) and the result is shown in Fig.12. The temperature decreases in proportion to the magnitude of B and B is proved to be a very important parameter.

5 CONSIDERATIONS

Table 2 shows the restriction level of SAR in ICNIRP Guidelines. As far as within the survey,power and antenna current are not so high and SAR did not exceed the level in Table 2.

However, many kinds of a mobile phone began to appear in market and successive study is needed.

Table2 Basic restrictions for time varying electric and magnetic fields of ICNIRP guidelines

Exposure characteristics	Frequency range	Localized SAR (head and trunk) ($W\ kg^{-1}$)
Occupational exposure	10 MHz–10 GHz	10
General public exposure	10 MHz–10 GHz	2

6 SUMMARY

The approach method of the effect of a mobile phone on a human body by FEM was introduced . Electromagnetic field, SAR and temperature rise can be obtained by the method. As far as within the survey,SAR does not exceed the restriction level of ICNIRP guidelines but succesive study is needed due to the existence of various kindes of a mobile phone.

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