UNIVERSITI PUTRA MALAYSIA

MODELING OF SPECIFIC ABSORPTION RATE DISTRIBUTION IN HUMAN HEAD DUE TO FAR FIELD ELECTROMAGNETIC WAVE RADIATION OF 900 MHZ AND 1800 MHZ USING THE METHOD OF MOMENT

NOR AZAH BINTI ABDUL AZIZ.

DEDICATION

To my beloved late dad, mum, families and hubby.

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirements for the degree of Master of Science

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In this study, a method of moment has been used to determine the induced electric field and specific absorption rate (SAR) distribution inside the human head due to far field electromagnetic wave radiation. Homogeneous and three layered spherical models were used to simulate a head of a two year old child at 900 MHz and 1800 MHz. In the models, the antenna was placed at 30 cm away from the head. The head was represented by 680 cells, suitable when using PC with Pentium IV processor and 512 MB DDR RAM memory. The method of moments (MOM) was employed to calculate the induced electric field which in turn can obtain the absorbed power, P_{abs}; localized SAR, SAR; and averaged SAR, SAR_{avg}. The results of the calculated SAR were presented for the far field case. For both homogeneous and three layered models, the value of SAR were found higher at frequency of 1800 MHz than 900 MHz. At both frequencies, the three

layered models have shown lower values of SAR. The results have shown the maximum absorbed power, localized SAR and averaged SAR are found in a homogeneous model at 1800 MHz, followed by three layered model at 1800 MHz, homogeneous model at 900 MHz and three layered model at 900 MHz. The averaged SAR for all models were in range 0.003 W/kg to 0.005 W/kg, which were still far behind the safety limit 0.08 W/kg averaged over 1 g of tissue. It was found that the behaviour of the localized SAR distribution were not uniform inside the head. It might be due to multiple reflection and absorption in the head. Besides, the incident electric field calculated in many angles might also contribute to the non-uniformity.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Master Sains

PERMODELAN TABURAN KADAR PENYERAPAN SPESIFIK DI DALAM KEPALA MANUSIA YANG TERHASIL DARI RADIASI GELOMBANG ELECTROMAGNET PADA 900 MHz ADAN 1800 MHz DENGAN MENGGUNAKAN KAEDAH MOMEN

Oleh

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Dalam kajian ini, kaedah momen telah digunakan untuk menentukan medan elektrik dan taburan kadar penyerapan spesifik (SAR) di dalam kepala manusia yang terhasil dari medan jauh radiasi gelombang elektromagnet. Model-model sfera yang sejenis dan tiga lapis digunakan untuk menyerupai kepala seorang budak yang berumur dua tahun pada frekuensi 900 MHz dan 1800 MHz. Dalam model itu, antenna diletakkan pada jarak 30 cm dari kepala. Kepala itu terdiri dari sebanyak 680 sel yang sesuai dengan penggunaan komputer peribadi dengan pemproses Pentium IV dan memori 512 MB DDR RAM. Kaedah momen (MOM) digunakan untuk mengira medan elektrik yang terhasil seterusnya dapat mengetahui kuasa serapan, P_{abs}; SAR setempat, *SAR*; and SAR purata, SAR_{avg}. Keputusan bagi *SAR* yang dikira disampaikan untuk kes medan jauh. Bagi

kedua-dua model sejenis dan tiga lapis, nilai SAR didapati lebih tinggi pada frekuensi 1800 MHz dari 900 MHz. Pada kedua-dua frekuensi, model tiga lapis telah menunjukkan bacaan yang lebih rendah. Keputusan telah menunjukkan kuasa serapan maksimum, P_{abs}; SAR setempat maksimum, SAR; and SAR purata maksimum, SAR_{avg} ditemui dalam model sejenis pada 1800 MHz, diikuti dengan model tiga lapis pada 1800 MHz, model sejenis padat 900 MHz dan model tiga jenis pada 900 MHz. Bagi kesemua model, SAR purata berada dalam julat 0.003 W/kg hingga 0.005 W/kg, di mana nilainya masih jauh dari had keselamatan 0.08 W/kg yang dipuratakan bagi 1 g tisu. Didapati juga, sifat taburan SAR setempat di dalam kepala adalah tidak seragam. Keadaan demikian mungkin disebabkan oleh pantulan dan penyerapan dari pelbagai sudut dalam kepala. Selain itu, medan elektrik insiden yang dikira dari pelbagai sudut juga boleh menyumbang kepada ketidakseragaman taburan tersebut.

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LIST OF ABBREVIATIONS

IEEE	- Institute of Electric and Electronic Engineers.
RF	- Radiofrequency.
ANSI	- American National Standard Institute.
NCRP	- National Council on Radiation Protection and Measurement.
IRPA	- International Radiation Protection Radiation
CENELEC	- European Committee for Electrotechnical Standardization
TIE	- Tensor Integral Equation.
IE	- Integral Equation.
EBCM	- Extended Boundary Condition Method.
IEBCM	- Iteractive Extended Boundary Condition Method.
FDTD	- Finite Different Time Domain.
MOM	- Method of Moment.
FEM	- Finite Element Method.
PDE	- partial differential equation.
FORTRAN	- Formula translation.
DDR RAM	- Double data rate random access memory.
PC	- personal computer.
SAR	- Specific Absorption Rate.
SAR	- localized SAR.
SAR_{avg}	- averaged SAR.
SAR_{max}	- maximum localized SAR.

$SAR_{av\,max}$	-	maximum averaged SAR.
P_{abs}	-	absorbed power.
P_{max}	-	maximum absorbed power.
dP	-	incremental electromagnetic power.
dm	-	incremental mass.
dV	-	volume element.
f	-	frequency.
π	-	pi = 3.141592654
j	-	imaginary part.
ε_0	-	free space permittivity.
μ_0	-	free space permeability.
ε_r	-	relative permittivity.
μ_r	-	relative permeability.
ε	-	permittivity.
μ	-	permeability
ε_c	-	complex relative permittivity.
μ_c	-	complex relative permeability.
ε'	-	real part of the complex relative permittivity.
ε''	-	imaginary part of the complex relative permittivity.
μ'	-	real part of the complex relative permeability.
μ''	-	imaginary part of the complex relative permeability.
ω	-	angular frequency.

t	-	elapsed time.
ρ	-	tissue density.
σ	-	tissue conductivity.
σ_{eff}	-	effective conductivity.
E_{rms}	-	root-mean-square (rms) value of the magnitude $\bar{E}$.
$\bar{E}^i$	-	incident electric field.
$\bar{E}^s$	-	scattered electric field.
$\bar{E}$	-	electric field intensity or induced electric field.
$\bar{H}^i$	-	incident magnetic field.
$\bar{H}^s$	-	scattered magnetic field.
$\bar{H}$	-	magnetic field intensity or induced electric field.
$\bar{D}$	-	electric flux density.
$\bar{B}$	-	magnetic flux density.
$\bar{J}$	-	electric current density (general).
ρ_f	-	electric charge density.
$\bar{\nabla}$	-	del operator.
$\bar{J}_e$	-	electric current density.
$\bar{J}_m$	-	magnetic current density.
$\bar{J}_{eq}$	-	equivalent current density in free space.
$\bar{r}$	-	field point.
$\bar{r}'$	-	source point.
τ	-	array storing value

$\vec{A}$	-	magnetic vector potential.
$\vec{G}$	-	vector Green's function.
G_0	-	free space scalar Green's function.
$\vec{G}_0$	-	free space dyadic Green's function.
$\vec{G}_{0x}$	-	free space vector Green's function with a source pointed in the x direction.
$\vec{G}_{0y}$	-	free space vector Green's function with a source pointed in the y direction.
$\vec{G}_{0z}$	-	free space vector Green's function with a source pointed in the z direction.
$\tilde{I}$	-	unit dyad or idem factor.
PV	-	principal value.
V	-	cell volume.
N	-	number of cell.
V_m	-	volume in cell m.
V_n	-	volume in cell n.
a_n	-	cell radius.
m	-	field cell.
n	-	source cell.
p, q	-	= 1, 2 and 3 indicated x, y and z respectively.
R_{mn}	-	distance between cell m and n.
$\vec{r}_m$	-	field point.

$\vec{r}_n$	-	source point.
α_{mn}	-	$k_0 R_{mn}$
$\cos\theta_{x_p}^{mn}$	-	$\dfrac{x_p^m - x_p^n}{R_{mn}}$
$\cos\theta_{x_q}^{mn}$	-	$\dfrac{x_q^m - x_q^n}{R_{mn}}$
$e^{j\omega t}$	-	time factor.
η	-	wave intrinsic impedance.
η_0	-	free space wave intrinsic impedance.
E_x	-	electric field in the positive *x*-direction.
H_y	-	electric field in the positive *y*-direction.
E-field	-	electric field.
H-field	-	magnetic field.
EM	-	electromagnetic.
E_{n1}	-	normal component of electric field in medium 1.
E_{n2}	-	normal component of electric field in medium 2.
ε_1	-	permittivity of material 1.
ε_2	-	permittivity of material 2.
E_{t1}	-	tangential component of electric field in medium 1.
E_{t2}	-	tangential component of electric field in medium 2.
$\hat{n}$	-	unit normal.
v	-	velocity of propagation in free space.

r	-	distance.
h	-	distance from cellular phone to observation point.
L	-	largest dimension of antenna.
E_0	-	electric field amplitude.
H_0	-	magnetic field amplitude.
λ	-	wavelength.
k_0	-	free space wave number.
k	-	wave number.
k_n	-	wave number of *n*th dielectric.
P_i	-	incident power density.
z	-	distance from antenna along z-axis.
z_0	-	distance from antenna to material surface in free space along z-axis.
z_n	-	distance between two material along z-axis.
α	-	attenuation constant.
δ	-	skin depth.
tan δ	-	loss factor or dissipation factor.
exp	-	exponent.
$\hat{x}$	-	unit vector in the positive x-direction.
$\hat{y}$	-	unit vector in the positive y-direction.
$\hat{z}$	-	unit vector in the positive z-direction.
W	-	Watt.

W/kg	-	Watt/kilogram.
g	-	gram.
F/m	-	Farads/meter.
H/m	-	Henrys/meter.
A/m	-	Amperes/meter.
C/m^2	-	Coulombs/meter^2.
$Weber/m^2$	-	Webers/meter^2.
A/m^2	-	Amperes/meter^2.
C/m^3	-	Coulombs/meter^3.
S/m	-	Siemens/meter.
rad/s	-	Radians/second.
V/m	-	Volt/meter.
m	-	Meter.
m^{-1}	-	permeter.
kg/m^3	-	Kilogram/meter^3.
W/m^2	-	Watt/meter^2.
cm	-	centimeter.
J	-	complex value (FORTRAN language).
KO	-	free space wave number (FORTRAN language).
EPSO	-	free space permittivity (FORTRAN language).
UO	-	free space permeability (FORTRAN language).
M	-	field cell – particular cell (FORTRAN language).
N	-	source cell – all cell (FORTRAN language).
NCELL	-	number of cell (FORTRAN language).

MXCLL	-	maximum number of cell (FORTRAN language).
MXCLL3	-	maximum dimension coefficient matrix (FORTRAN language).
F	-	frequency of cell N (FORTRAN language).
W	-	angular frequency of cell N (FORTRAN language).
X(1,N)	-	*x* component of cell N (FORTRAN language).
X(2,N)	-	*y* component of cell N (FORTRAN language).
X(3,N)	-	*z* component of cell N (FORTRAN language).
V(N)	-	volume of cell N (FORTRAN language).
SIGMA(N)	-	conductivity of cell N (FORTRAN language).
EPS(N)	-	permittivity of cell N (FORTRAN language).
RHO(N)	-	density of cell N (FORTRAN language).
TAU(N)	-	array storing value of cell N (FORTRAN language).
S(N)	-	mass of cell N (FORTRAN language).
X(1,M)	-	*x* component of cell M (FORTRAN language).
X(2,M)	-	*y* component of cell M (FORTRAN language).
X(3,M)	-	*z* component of cell M (FORTRAN language).
DIST	-	distance between cell M and N (FORTRAN language).
EI(N)	-	concatenated matrix of incident electric field (FORTRAN language).
EIR(N)	-	real part of incident electric field (FORTRAN language)
EIR(N)	-	imaginary part of incident electric field (FORTRAN language)
E(N)	-	concatenated matrix of induced electric field (FORTRAN language)
G	-	coefficient matrix (FORTRAN language).

X1	-	row location in G-matrix (FORTRAN language).
X2	-	column location in G-matrix (FORTRAN language).
P	-	= 1, 2 and 3 represent *x*, *y* and *z* respectively (FORTRAN language).
Q	-	= 1, 2 and 3 represent *x*, *y* and *z* respectively (FORTRAN language).
POW(N)	-	absorbed power in cell N (FORTRAN language).
SAR(N)	-	SAR in cell N (FORTRAN language).
AVSAR(N)	-	averaged SAR in cell N (FORTRAN language).
A	-	concatenated matrix (FORTRAN language).
IRMAX	-	maximum row dimension of A and X matrix (FORTRAN language).
IRMAX1	-	maximum column dimension of A matrix (FORTRAN language).
N	-	actual row dimension (FORTRAN language).
M	-	actual column dimension (FORTRAN language).
X	-	output G-Matrix (FORTRAN language).
ITMA	-	Institute of Advanced Technology.
FSAS	-	Faculty of Science and Environmental Studies.

CHAPTER 1

INTRODUCTION

1.1 Introduction

Beginning in 1950s, wireless communication services become a major consumer in paging and cellular telephony. Since then, both services dominated in consumer marketplace. At the end of 1994, paging and cellular telephone had grown to a worldwide market serving 50 million and 52 million users representing a growth rate of 40% and 58% respectively [1].

In most developing countries, cellular phone is emerging as the wireless technology of choice for basic telephone service. With the growth of the cellular phone usage and design, it becomes a necessity to have a rapid and precise method to calculate and measure the electromagnetic field in human tissue.

A number of key market and technology forces are driving the growth in the wireless communications. They can be summarized as follows:

1. The demand to improve productivity, safety communication, responsiveness and the quality of life that wireless communication can provide.
2. The shift to global economy as well as the changing and political scene in international markets has opened up new opportunities for all technologies.