Interaction of EM Radiation Emitted From Mobile Phones and the Human Brain Tissues

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***Abstract** - In this paper, we describe the interaction of electromagnetic waves with human brain. In particular, power dissipation mainly in human brain parts such as white matter, Gray matter, Cerebellum, muzzles, Skin eyes and bones is studied. For this purpose, an FDTD code has been developed to calculate specific absorption rates in the human head.*

To achieve this goal:

- *A 3D FDTD Visual Basic (VB) code has been designed including a PML mesh truncation and human head model.*
- *The tissue distribution in a human head is extensively studied to model the object successfully.*
- *Measure the radiation output of various mobile phones (When communicating via normal mobile communication, wi-fi communication and the Bluetooth communication)and calculate SAR value for those various phones.*
- *Calculate the safety time period of a mobile phone can be used continuously.*

Keywords— MoM, FEM, FDTD,SAR

I. INTRODUCTION

During the 20th century, environmental exposure to man-made electromagnetic fields has been steadily increasing as growing electricity demand, ever-advancing technologies and changes in social behaviour have created more and more artificial sources. Wireless communication links have been used worldwide for many years as solutions for connectivity in point-to-point and point-to multipoint applications. The most common wireless solutions include AM and FM radio television broadcast stations, mobile and cellular phones, radar and microwave systems. The following two questions aerie when doing this research

- What are the effects of radio waves on human health?
- What health risks are associated with the use of cell phones, mobile radios, microwave radios, microwave ovens, broadcast radio and television transmitters, power lines and X-rays?

Small electrical currents exist in the human body due to the chemical reactions that occur as part of the normal bodily functions. For example, nerves relay signals by transmitting electric impulses and brain activities go along with the rearrangement of charged particles. And also the heart is electrically actives.[2]

Both electric and magnetic fields induce voltages and currents in the body but even directly beneath a high voltage transmission line, the induced currents are very small compared to thresholds for producing shock and other electrical effects.

One basic interaction is the absorption of energy from the electromagnetic frequency which can cause tissue to heat up, more intense field exposures will produce greater heating. This heat deposition can lead to biological effects ranging from discomfort to protein penetration to burns.

II. ELECTROMAGNETIC RADIATION

The term "electromagnetic field" is used to indicate the presence of electromagnetic energy at a given location. The RF field can be described in terms of the electric and/or magnetic field strength at that location. The Electromagnetic Radiation can be divided into two types according to the energy containing [3].They are

A. *Ionizing Radiation*

Electromagnetic energy is carried by photons. The higher the frequency, the higher the energy in each photon. Ionizing radiation is radiation with enough energy so that during an interaction with an atom, it can remove tightly bound electrons from the orbit of an atom, causing the atom to become charged or ionized[5]

B. *Non Ionizing Radiation*

The lower part of the frequency spectrum is considered non-ionizing Electromagnetic Radiation (EMR), with energy levels below that required for effects at the atomic level. Non-ionizing radiations (NIR) encompass the long wavelength (> 100 nm), low photon energy (< 12.4 eV) portion of the electromagnetic spectrum, from 1 Hz to 3 GHz.[5]

III. BIOLOGICAL EFFECTS OF DUE TO EM EXPOSURE

The human body is made of a large number of materials and each of them having specific properties. These properties have been extensively studied in the last fifty years from 10 Hz to almost 10 GHz [3,4].

According to the researches biological tissues mainly consist of water, they behave neither as a conductor nor a dielectric, but as a dielectric with losses. It is also shown that electromagnetic properties values are highly depending on the frequency.

Radio Frequency Radiation Effects

RF energy in the frequency range of LF, MF, HF VHF, UHF or Microwaves is often referred to as radio waves, RF radiation, or RF emissions.[8]

In this project I consider, the term “RF energy” is used for all frequencies between 1MHz and 10GHz. Some known facts about RF energy are:

- The biological effects of RF energy are proportional to the rate of energy absorption, and the level of absorption varies little with frequency.
- Biological effects that result from heating of tissue by RF energy are often referred to as "thermal" effects. This is like the way that microwave ovens heat food, and can be hazardous if the exposure is sufficiently intense or prolonged.
- Damage to tissue may be caused by exposure to high levels of RF energy because the body is not equipped to dissipate the excessive amounts of heat generated. Possible injuries include skin burns, deep burns, heat exhaustion and heat stroke.

Eyes are particularly vulnerable to extended exposure to RF energy heating because of the relative lack of available blood flow to dissipate the excessive heat load (blood circulation is one of the body’s major mechanisms for coping with excessive heat).

IV. HUMAN BRAIN

The brain is probably the most complex structure in the known universe. The human brain consists of roughly three separate parts.

- The brain stem
- The midbrain
- The forebrain

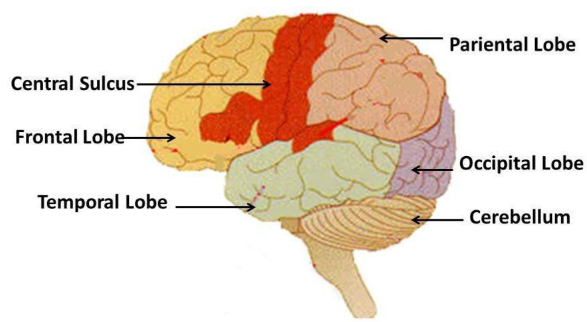

Figure1: The Main Parts of the Brain

Brain Facts & Figures Required for 3D Modeling

- Average Brain Weights (in grams) - 1,300 - 1,400
- Average brain width - 140 mm
- Average brain length - 167 mm
- Average brain height - 93 mm

V. NUMERICAL SOLUTION OF ELECTROMAGNETIC

The accurate determination of electromagnetic fields within an arbitrary inhomogeneous living tissue is a complicated problem there are numbers of researches has been carried out upon this and the effects of microwave upon living tissue. Electromagnetic radiation or scattering problems may be modeled as initial or boundary value problems governed by partial differential equations subject to properly defined initial or boundary values.

The spatial domain of the initial or boundary value problem may be quite complicated in general, and the direct analytical solution of the problem is usually impossible. To this end, several approximate solution techniques have been developed so far, the most important ones being the

- Method of Moments (MoM)
- The Finite Element Method (FEM)
- The Finite Difference Time Domain (FDTD) method

VI THE FINITE DIFFERENCE TIME DOMAIN (FDTD) METHOD

The basic FDTD space grid and time-stepping algorithm trace back to a seminal 1966 paper by Kane Yee in IEEE Transactions on Antennas and Propagation.[1]

The FDTD method belongs in the general class of differential time domain numerical modeling methods. Maxwell's (differential form) equations are simply modified to central-difference equations, discritized, and implemented in software. The equations are solved in a leap-frog manner; that is, the electric field is solved at a given instant in time, then the magnetic field are solved at the next instant in time, and the process is repeated over and over again.[1][6][7]

The Yee Algorithm

Finite difference approximation by using the central difference expressions for both space and time derivatives.

Yee introduce a set of finite difference equations for the system of following Yees's notation a grid point in the solution region can be introduce as

$$(i , j , k) = (i\delta_x , j\delta_y , k\delta_z)$$

And any function of space and time as

$$F^n(i , j , k) = F (i\delta_x , j\delta_y , k\delta_z , n\delta t)$$

Where $\delta = \delta_x = \delta_y = \delta_z = \delta$ is the space increment , δt is the time increment while i,j,k,n are integers.

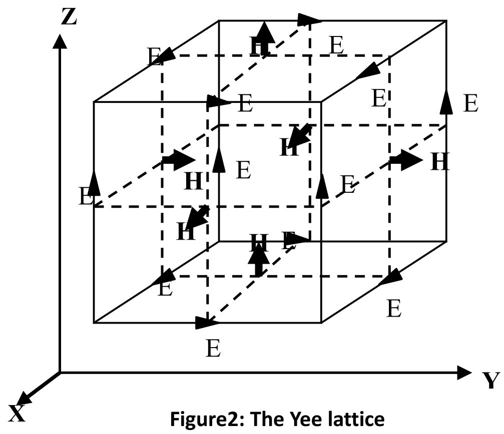

Figure2: The Yee lattice

The Yee cell representing the building block of the FDTD grid. As shown above, every E component is surrounded by four circulating H components, and every H component is surrounded by four circulating E components.

Furthermore, Yee proposed a leapfrog scheme for marching in time wherein the E-field and H-field updates are staggered so that E-field updates are conducted midway during each time-step between successive H-field updates, and conversely.

H_x at the time step n+1 is evaluated in terms of previously calculated values of H_x (at the time step n), E_y and E_z (at time step n+ 1/2).

$$H_{x\,i,j+\frac{1}{2},k+\frac{1}{2}}^{\,n+\frac{1}{2}} = H_{x\,i,j+\frac{1}{2},k+\frac{1}{2}}^{\,n-\frac{1}{2}} + \frac{\delta t}{\delta\left(\mu_{i,j+\frac{1}{2},k+\frac{1}{2}}\right)}[E_{y\,i,j+\frac{1}{2},k+1}^{\,n} - E_{y\,i,j+\frac{1}{2},k}^{\,n} - E_{z\,i,j+1,k+1/2}^{\,n} + E_{z\,i,j,k+1/2}^{\,n}]$$

In a similar manner, we can derive the finite-difference expressions for other two equations get expression for $H_{y\,i+1/2,j,k+1/2}^{\,n+1/2}$ and $H_{z\,i+\frac{1}{2},j+1/2,k}^{\,n+1/2}$.

And for the electric field

$$E_{x\,i+\frac{1}{2},j,k}^{\,n+1} = \left(\frac{1-\frac{\sigma\delta t}{2\varepsilon}}{1+\frac{\sigma\delta t}{2\varepsilon}}\right)E_{x\,i+\frac{1}{2},j,k}^{\,n} + \left(\frac{\frac{\delta t}{\varepsilon}}{\delta(1+\frac{\sigma\delta t}{2\varepsilon})}\right)(H_{z\,i+\frac{1}{2},j+\frac{1}{2},k}^{\,n+1/2} - H_{z\,i+\frac{1}{2},j-\frac{1}{2},k}^{\,n-1/2} - H_{y\,i+\frac{1}{2},j,k+\frac{1}{2}}^{\,n+1/2} + H_{y\,i+\frac{1}{2},j,k-\frac{1}{2}}^{\,n-1/2})$$

VII. COMPUTATIONAL CHANGES IN YEE'S ALGORITHMS

The above equations cannot directly apply to the computational domain. So by applying several conditions it has to be change. The modified equations as follows :

$$\widetilde{E_x}(I,J,K) = CA_x\,\widetilde{E_x}(I,J,K) + CB_x[\widetilde{H_z}(I,J,K) - \widetilde{H_z}(I,J-1,K) - \widetilde{H_y}(I,J,K) + \widetilde{H_y}(I,J,K-1)\,]$$

$$H_x\,(I,J,K) = H_x\,(I,J,K) + \frac{1}{2}[\widetilde{E_Y}(I,J,K+1) - \widetilde{E_Y}(I,J,K) - \widetilde{E_z}(I,J+1,K) + \widetilde{E_z}(I,J,K)]$$

Similar manner we can modified the $\widetilde{E_y}(I,J,K)$, $\widetilde{E_z}(I,J,K)$, $H_y\,(I,J,K)$ and $H_z\,(I,J,K)$.

The 3dimenional visual Basic coding as follows :

```
Ex1(px1, py1, pz1) = CA * Ex1(px1, py1, pz1) + CB *
   (Hz1(px1, py1, pz1) –    Hz1(px1, py1 - 1, pz1) +
   Hy1(px1, py1, pz1 - 1) - Hy1(px1, py1, pz1))
Hx1(px1, py1, pz1) = Hx1(px1, py1, pz1) + 0.5 *
   (Ey1(px1, py1, pz1 + 1) - y1(px1, py1, pz1) +
Ez1(px1,              py1, pz1) - Ez1(px1, py1 + 1, pz1))
```

Where the

$$CA\ (I,J,K) = \frac{1-\frac{\sigma_{i+\frac{1}{2},j,k}\delta t}{2\varepsilon_{i+\frac{1}{2},j,k}}}{1+\frac{\sigma_{i+\frac{1}{2},j,k}\delta t}{2\varepsilon_{i+\frac{1}{2},j,k}}}$$ and

$$CB\ (I,J,K) = \frac{\sqrt{\frac{\varepsilon_0}{\mu_0}}\frac{\delta t}{\varepsilon_{i+\frac{1}{2},j,k}}}{\delta\left(1+\frac{\sigma_{i+\frac{1}{2},j,k}\delta t}{2\varepsilon_{i+\frac{1}{2},j,k}}\right)},$$

VIII. SAR CALCULATIONS

Specific absorption rate (SAR) is a measure of the maximum rate at which radio frequency (RF) energy is absorbed by the body when exposed to radio-frequency electromagnetic field. It is used for exposure to fields between 100kHz and 10 GHz.[9]

In tissue, SAR is proportional to the square of the internal electric field strength. Average SAR and SAR distribution can be computed or estimated from laboratory measurements. Values of SAR depend on the following factors:

- The geometry of the part of the body that is exposed to the RF energy such as its size and internal and external geometry, and the dielectric properties of the various tissues
- The exact location
- Geometry of the source of the RF energy
- The incident field parameters, such as the frequency, intensity, polarization, and source object configuration (near- or far-field)
- Ground effects and reflector effects of other objects in the field near the exposed body

There are two sets of limits,

- General public exposure
- Occupational exposure.

They are further subdivided into three categories as follows:

- Whole body averaged SAR
- Localized SAR in the head and trunk
- Localized SAR in the limbs.

But in this paper we consider only General public exposure. As the EM field is being stepped through the scatter, a peak detector is constantly monitoring each point for a new maximum amplitude. When steady state reach these stored values of maximum amplitude are retained.

When related to *sinusoidal* E-field at a point(x,y,z) in tissue , SAR is given by

$$SAR_{(x,y,z)} = \sigma_{(x,y,z)(E_{(x,y,z)})}\backslash 2\rho_{(x,y,z)}$$

Where

σ = conductivity of the tissue (S/m)

ρ = mass density of the tissue (kg/m^3)

E = rms electric field strength (V/m)

By using FDTD method SAR calculation or the distribution of the body down in following way.

For 3D

$$SAR(i\,,j\,,k) = \frac{1}{2\rho}\left(\sigma_x(i,j,k)E_{x_{max}}^2 + \sigma_y(i,j,k)E_{y_{max}}^2 + \sigma_z(i,j,k)E_{z_{max}}^2\right)$$

Where the ρ is the mass density of the tissue in Kg/m^3

The highest value of these maximum amplitude from all the cells is selected to calculate the worst case SAR (SAR_W) value

$$SAR_W = \frac{\text{Maximum SAR value }(\frac{W}{Kg})}{\text{Volume of a cubical cell}(cm^2)}$$

Consider SAR values for FM radio, TV and mobile cellular base stations SAR_{TV} , SAR_{FM} and SAR_{mobile} number of channel from each in rage N_1 , N_2, N_3 respectively, so then the maximum possible SAR_w due to all considered networks of a location is that

SAR_w of the location site = SAR_{TV} * N_1 + , SAR_{FM} * N_2 + SAR_{mobile} * N_3

In this paper we mainly consider the or assume the field components E_z and H_y and proper gate along the +y direction.

This is the maximum EM energy absorption occur when the incident electric field is aligned with the long axis of the object i.e the Z axis

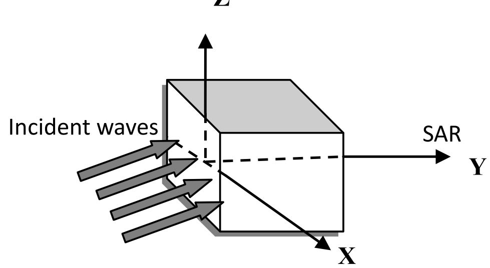

Figure3: The Radiation Interaction

IX. HUMAN BRAIN MODEL FOR THE USE IN FDTD APPLICATIONS

A. The Size Of The Cell

To get accurate results, the grid spacing or the spatial increment δ in the finite difference simulation must be less than the wavelength or the minimum dimension of the scatter usually less than λ/10.

$\delta \le 1/\lambda = \frac{0.1\,c}{f\sqrt{\varepsilon_r}}$ Where ε_r= Highest permittivity

B. Modeling human brain by using MRI scans images and apply the lattice truncation conditions

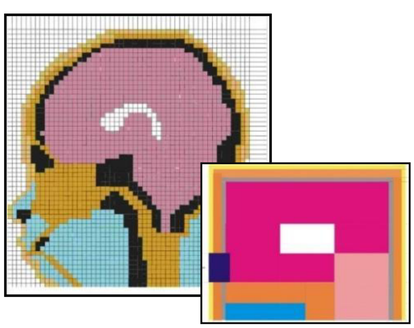

Figure 4. The FDTD model of the human head in X – Y plane

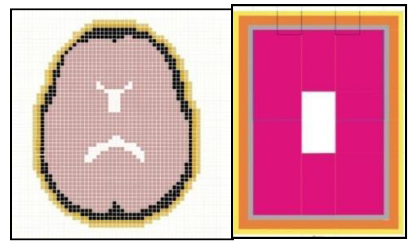

Figure5. The FDTD model of the human head in Y – Z plane

X. MEASUREMENTS AND OBSERVATIONS

A. Heating effect due to SAR

The absorption of EM energy increases the temperature of body tissues. The temperature increase can be measured using following equation [11]

$$SAR = c\,\frac{\Delta T}{\Delta t}$$

Where c = 3.5 kJ/Kg°C

ΔT = change in temperature (ºC)

Δt = duration of exposure (s)

C = specific heat capacity (J/kg ºC)

B. SAR Value for Several Mobile Phone Brands

In this research I used several popular mobile phone brands and the models, measure the power output using a Spectrum Analyzer. Then used the developed software for calculate the Localized SAR in the head and trunk for each of the mobile phone type. The SAR values are shown in following table:

Mobile Phone Brands	Mobile Phone Models	SAR Value in W/Kg
Nokia	1100	0.98
	1110	1.15
	1600	1.12
	2600	0.99
	3100	1.17
	5300	0.89
	6100	1.19
	N70	0.76
	N95	1.17
	Nokia Lumia 610	0.83
Motorola	C550	0.71
	C650	0.87
	W370	0.90
Samsung	Galaxy S III 4G	0.98
	GT-I9100 Galaxy S II	0.34

	GT-S5570 Galaxy Mini	0.96
	GT-S5620 Monte	1.20
	SGH-E100	0.89
Apple	Apple iPad	0.88
	Apple iPad 2	0.98
	Apple iPhone	0.974
	Apple iPhone 5	0.901
	Apple iPhone 5S	0.98
Sony Ericsson	Z300i	0.75
	Z610i	1.32

Table 1: The Calculated SAR Value for different mobile phones (Head)

C. Continuous Talking Safety time for a Mobile Phone

According to the some of the researches it said that the rise of the temperature of the body tissue by 1 ^{0}C will lead to change the internal characteristics of the tissues. Further long term exposure to the EM radiation will have a higher probability for cancer.

Then substituting the values of ΔT = 1℃ and c = 3.5 kJ/Kg℃ for SAR calculation equation

$$SAR = \frac{3500W}{s\text{Kg℃}} \quad \frac{1\text{℃}}{\Delta t}$$

Example

Nokia 1100 has 0.98W SAR value then the safety time t,

$$t = \frac{3500}{0.98}\ \text{s} = 3571.43\text{s} = 0.99\ \text{hrs}$$

Mobile Phone Brands	Mobile Phone Models	Safe Time Period	
		In Seconds	In Minutes
Nokia	1100	3,571.43	59.52
	1110	3,043.48	50.72
	1600	3,125.00	52.08
	2600	3,535.35	58.92
	3100	2,991.45	49.86
	5300	3,932.58	65.54
	6100	2,941.18	49.02
	N70	4,605.26	76.75
	N95	2,991.45	49.86
	Nokia Lumia 610	4,216.87	70.28
Motorola	C550	4,929.58	82.16
	C650	4,022.99	67.05
	W370	3,888.89	64.81
Samsung	Galaxy S III 4G	3,571.43	59.52
	GT-I9100 Galaxy S II	10,294.12	171.57
	GT-S5570 Galaxy Mini	3,645.83	60.76
	GT-S5620 Monte	2,916.67	48.61
	SGH-E100	3,932.58	65.54
Apple	Apple iPad	3,977.27	66.29
	Apple iPad 2	3,571.43	59.52
	Apple iPhone	3,593.43	59.89
	Apple iPhone 5	3,884.57	64.74
	Apple iPhone 5S	3,571.43	59.52
Sony Ericsson	Z300i	4,666.67	77.78
	Z610i	2,651.52	44.19

Table 2: The Calculated safety time period for mobile phones (Continuous)

XI CONCLUSION

The mobile phone model which I implemented with the software has to been studied further and has to develop. The Bluetooth, Wi-Fi, WI Max effects is not consider but there may be effects so those fields also taken into consideration in theoretical estimation of the SAR. The same method which applied to the inhomogeneous nature of the human brain can be applied to the other body parts such as eye, heart, kidney etc and can estimate SAR value.

The long term studies have to been carried out to get the biological effects on the EM radiation to human in Sri Lanka. The main contribution of this Paper is the development of an FDTD code to study the interaction of electromagnetic waves emitted from a mobile phone with the human brain inhomogeneous tissues.

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Temperature and SAR Calculations for a Human Head Within Volume and Surface Coils at 64 and 300 MHz

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Thushara Lanka Weerawardane graduated in electrical engineering from University of Moratuwa in 1998. After that, he worked as an assistant network manager in the department of electrical engineering and as a system engineer for LEARN from 1999 to 2002. He got his master degree and doctoral degree from University of Bremen in Germany in 2004 and 2010 respectively. He worked as a Scientist at the department of communication networks in an industrial research project of Nokia Siemens Company, Germany from 2004 to 2012. He worked as a Scientist and Industrial Project Coordinator, University of Bremen, Germany and also worked as a Lecturer and Project Leader University of technology Hamburg in Germany. Currently he is working as a Senior Lecturer Grade 1, Department of Electrical, Electronic & Telecommunication and Head of the Department Mathematics at Kotelawala Defence University in Sri Lanka.

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