An Investigation of Electromagnetic Field Effect On a Human Skin Cell Using Numerical Method Approaches

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Abstract—**the investigation between electromagnetic waves (conduction current) and human cell as lossless material has received renewed attention recently. This propagation can come from many sources such as cellular phone. The structure of a human cell were studied from many school of thinking such as biochemical in cell, cytoplasm, nucleus and membrane and the understanding obtained have been used as the basis in the developing of mathematical model. The main objective of this project is to analyze the behavior and determine the parameters of the interaction and propagation in a single cell when expose to electromagnetic wave from lossy material to lossless material such as the attenuation coefficient, electric field and skin depth. The Maxwell equations were used as the basis of the modeling in this project with aid of numerical method approaches specifically Finite-Difference Time Domain (FDTD) techniques and applications. To develop the model MATLAB tool and Graphical Users Interface (GUI) were used. Results obtained from the developed model ware verified with known result obtained from others researchers and with experimentally.**

Keywords-electromagnetic wave, finite difference time domain, attenuation coefficient

1. INTRODUCTION

The total effects resulting from the interaction between electromagnetic radiation and biological tissue can be regarded as a combined effect of three phenomena that is the penetration of electromagnetic waves (EM) into the live system, the spread of the wave into the tissue [1] and other possible secondary effects that were induced from primary interactions [2].

The word interaction is important because it stresses the fact that the end results do not depend on only the action of the field but also being influenced by the reaction of the living system. Living systems have a large capacity for compensating the effects induced by external influences, in particular EM sources. Although usually this is overlooked it is one main reason for which conclusions derived from models have to be taken with precaution. Physiological compensation means that strain imposed by external factors is fully compensated and the organism is able to perform normally.

The radiation of the considered mechanism consists of a source that emits EM energy. Part of the incident energy is absorbed and transformed within the biological system [3]. Hence, there is the sequence source-radiation-target. The physical laws of EM field theory, reflection, diffraction, dispersion, interference, optics and quantum effects, must be applied to investigate and explain the observed phenomena.

The increased rate of industrial growth in the world today and the tendency of companies to improve the power and quality of their equipment had raised questions about the health risks of industrial workers and the general public. Therefore this occurrence provides an impetus to carry out large research projects and to collect a large amount of experimental data and clinical observations. Before starting any interpretation with respect to the obtained, it is necessary to revise the basic phenomena involved in the interaction of electromagnetic radiation with living systems. For the first step it is important to understand the basic analysis bio-electromagnetic.

2. STRUCTURE AND SIZE OF HUMAN SKIN CELL

National Institute of General Medical Sciences (NIGMS) USA has carried out its research on human skin cell sizes in 2008[2]. The size was reported as shown in table below. The data on the skin cell sizes is very important because it was used in modeling the structure of cell in MATLAB software.

Table 1: Human skin cell size

Cell partition	Actual Size (average)
Cell diameter	40 micrometer
Nucleus thickness	5 micrometer
Membrane thickness	4 micrometer
Substances thickness	20-30 micrometer

3. CELL MEMBRANE EFFECT

The biological action of low intensity non-ionizing electromagnetic radiation on molecular and supermolecular level was first established. The electromagnetic fields induce the emergence of the electric charges on cell membrane that later on would bring the additional electric potential on cellular membrane. The microwave radiation causes significant changes on different type of cell membrane characteristics; basically it induces increase of membrane permeability for sodium, potassium and chlorine ions and inhibits the active transport of these ions via lipid membranes [6].

4. NUMERICAL SOLUTIONS FOR HUMAN CELL

Numerical solutions can be categorized into the domain solution, which includes the whole domain as the operational area, and the boundary solution. The former is also called a differential solution, and the latter, an integral solution [4]. The domain solutions include the finite difference time domain (FDTD) method in which it is a simple numerical technique that is used in solving problems that are uniquely defined by three things:
1) A partial differential equation such as Laplace's or Poisson's equation
2) A solution region
3) Boundary and/or initial conditions

A finite difference time domain method such as Poisson's or Laplace's equation proceeds in three steps:
1) Dividing the solution region into a grid of nodes
2) Approximating the differential equation and boundary conditions by a set of linear algebraic equations (difference equations) on grid points within solution region.
3) Solving this set of algebraic equations.

The basic formulation that governs the propagation of wave in the human skin cell is Maxwell's equations and it derives to be equation 1 to obtaining electromagnetic field (E-field) [5].

$$E(i,j) = \frac{E(i+1,j)+E(i-1,j)+\left(\frac{\Delta x^2}{\Delta y^2}\right)(E(i,j+1)+E(i,j-1))}{2\left(1+\left(\frac{\Delta x^2}{\Delta y^2}\right)^2\right)-\Delta x^2\left(k_0^2 n^2(i,j)-\beta^2\right)}$$
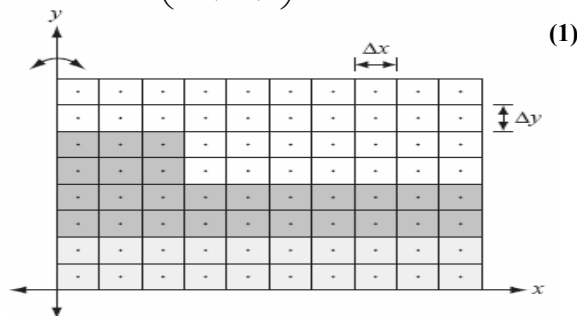
(1)

Figure 1: A typical finite difference mesh for an integrated wave propagation. The electric field profile, $E(x, y)$ has been divided into small rectangular cells .

5. CELL STRUCTURE

In the MATLAB, cell structure is designed following the standard from NIGMS cell size measurement. The cell consists of three parts which are the three-layer membrane, chemical substances and nucleus.
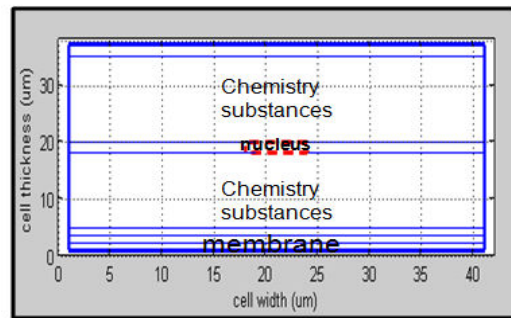

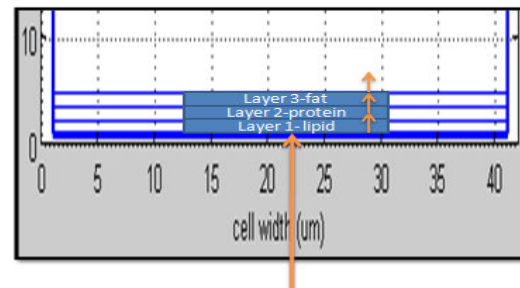
Figure 2 (a): cell structure and partition

Lossless electromagnetic wave

Figure 2(b): three-layer membrane cell, layer 1=lipid, layer 2=protein and layer 3=fat

6. ASSUMPTIONS

In this project the three assumptions were made; the cell is considered as a box and has a flat surface (Figure 3(a)). In addition, the wave is propagated from only one source and transmits only on one side of a cell (Figure 3(b)). The cell will become damaged once the electromagnetic waves able to penetrate deep into the nucleus (Figure 3(c)).
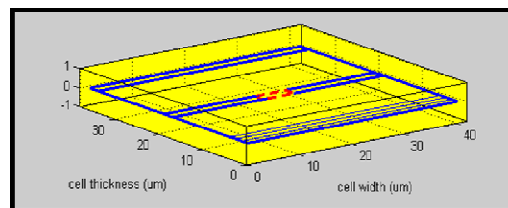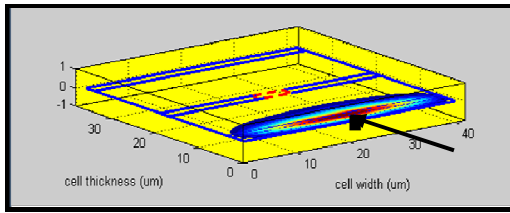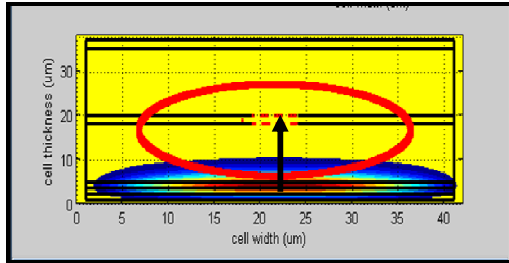

Figure 3(a)

Figure 3(b)

Figure 3(c)

7. THE PARAMETER CONSIDERED IN MATLAB DESIGN.

Based on the wave sources, permittivity and conductivity parameters are to be considered in the MATLAB simulation. Parameter was taken based on four-sample frequencies which are 2.36 GHz, 4.5GHz, 9GHz and 15GHz because frequently using in designing devices. The permittivity and conductivity for each sample frequency is as shown in Table 2.

Table 2: permittivity and conductivity parameter [1]

Frequencies (Hz)	layer1(lipid)		layer2(protein)		layer3(fat)	
	σ_{eff} (S/M)	ε_r	σ_{eff} (S/M)	ε_r	σ_{eff} (S/M)	ε_r
2.36GHz	0.61	53	0.5	44.6	0.04	17.03
4.5GHz	0.72	51.31	0.55	42.48	0.05	15.03
9 GHz	0.87	41.4	0.59	38.9	0.11	11.3
15GHz	1.19	39	0.92	37	0.19	11

8. ELECTROMAGNETIC WAVE AT FREE SPACES

The distance between the cellular source of electromagnetic waves and human cells was set to 10 meters. Table 3 shows the parameters of electromagnetic waves at a different frequency value in free space. Assuming that the wave moves at the velocity $V_P = 3x10^8$ (m/s) this means that electromagnetic waves propagate very quickly at the highest frequency before entering human cells. Free spaces is consider lossy material which weak conductor but when wave at free spaces started to interact with human skin cell, the kinetic energy will produce work and and power. Power will yield from current conduction based on resistance in human cell.

The value of electric field will obtained based on electric flux density and permittivity (free spaces and relative permittivity)

Table 3: Electromagnetic wave parameter at lossless material in different frequency.

frequency	Free space velocity, v_p (m/s)	Wavelength, Λ (m)	Propagation constant, β (rad/m)
2.36GHz	$3x10^8$	0.13	49.4
4.5GHz	$3x10^8$	0.07	96.2
9GHz	$3x10^8$	0.03	188
15GHz	$3x10^8$	0.02	814

9. AN INTERACTION OF EM ON A HUMAN SKIN CELL

Human cell is lossless dielectric material and its can produce a very good and perfect conductor [1]. EM wave propagation in cell depends on attenuation coefficient and skin depth to measure the percentage of electric field in cell. From the MATLAB simulation the orange contour shows how the E-field penetrates into the human cell from layer 1 (lipid) to layer 2 (protein) and layer 3 (fat). At 2.36 GHz the E-field contour was refracted to chemicals and nucleus as shown at figure 4(a). On the contrary, at 4.5 GHz in which after penetrating the third layer (fat), the pattern of the contour propagate only chemicals in the human skin cell as shown in Figure 4(b). At 9 GHz the contour patterns are found nearly at the third layer of the cell membranes which electromagnetic waves propagating not very far away as shown in Figure 4(c). This indicates that the high frequency electromagnetic waves cannot propagate in a far distance and electric field cannot penetrate the cell other that the cell membrane. In contrast to the low frequency, the wave can penetrate more than the cell membrane.
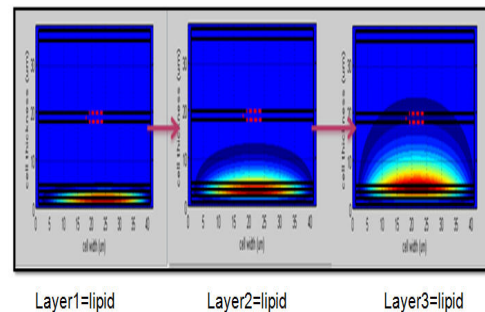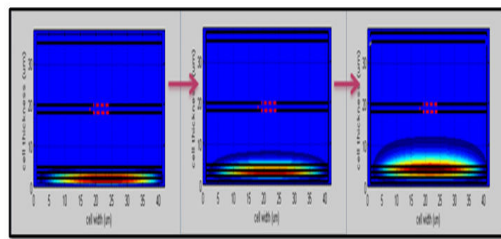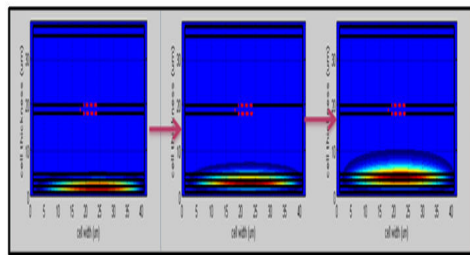

Layer1=lipid   Layer2=lipid   Layer3=lipid

Figure 4(a): Movement of E-field at 2.36 GHz

Figure 4(b): Movement of E-field at 4.5 GHz

Figure 4(c): Movement of E-field at 9 GHz

10. THE VALUE OF E- FIELD FROM MATLAB SIMULATION

When the electromagnetic wave propagates from a transmitter source to human skin cells, it will first interact with the cell membranes. The value of electromagnetic field (E-field) at wave interact with cell, E_0 was obtained when the E-field is at its highest in the first layer. When the wave propagates in the second layer and so on, the electromagnetic field will decrease due to absorption of energy in human cells. E_0 vs. layer graph shows an exponential decay of the E_0. When the frequency increases, E_0 will decrease and the wave cannot penetrate far in cell.

When electromagnetic wave penetrates the second and third layer more energy will be absorbed by the cell and it causes E_0 to be reduced. Table 4 and figure 5, correspondingly shows the comparison table and graph that is to compare the value of E_0 at different membrane layer and frequency.

Table 4: Comparison table of E_0 at different membrane layer, and frequency

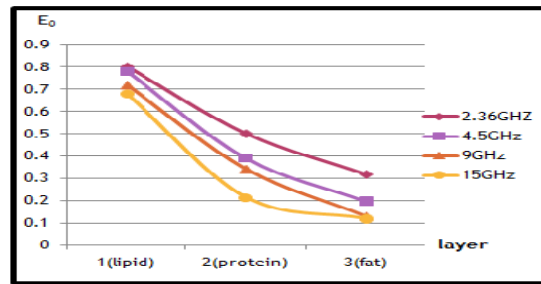| frequency	layer1(lipid)	layer2(protein)	layer3(fat)
2.36GHz	0.8	0.5	0.32
4.5GHz	0.78	0.39	0.2
9GHz	0.72	0.34	0.13
15GHz	0.68	0.21	0.12

Figure 5: Comparison figure of E_0 at different membrane layer, and frequency.

11. VERIFICATION OF THE RESULT

The frequency dependence of relative permittivity ε (x) and conductivity σ (0) for Magnetic resonance Imaging (MRI) sources [6]. Comparing with this literature, the results obtained from this project shows that if the value of frequency increases, there will be an increase in the conductivity σ (0) and decrease the permittivity ε (x). Therefore by increasing the frequency, it will increase the attenuation and in contrast decrease the skin depth. It will affect the value of electrical field and propagation of the electromagnetic wave. The project analysis also proved that MRI exhibit the same scenario as cellular phone and the electromagnetic wave could propagate deep into a human skin cell at 2.36GHz. Another comparison with experimentally result which at range 2-3 GHz they have active foreign particle in human cell than others frequency. The particle maybe virus or bacteria and causing the cell damage.

12. CONCLUSION

The size of human skin cells were taken from an actual size and been modeled by using MATLAB software. From the simulation results, at 2.36 GHz the electric field was found to be larger than the other frequency values and the probability of the electric field up to the nucleus was also high and the attenuation value was decreased. At 2.36 GHz attenuation values were found lower and the skin depth was high. This shows that the electromagnetic waves can propagate over a long distance in a lower frequency. Assuming that the electromagnetic waves were able to propagate into the nucleus and the electromagnetic field was still high in the third layer of membrane, human skin cells will become damaged. The damaged cell may cause various diseases such as skin cancer and therefore, rather dangerous to human and likewise other inhabitant of earth. From this finding, it is strongly encourage that the telecommunications company and related industries should design their equipment at a suitable frequency based on currently medical research or academic research.

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