International Journal of Natural and Engineering Sciences
E-ISSN: 2146-0086 12(2): 20-23, 2018

Calculation of Specific Absorption Rate at Four Tissue Layers Using One Dimensional FDTD Method

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Abstract
The wider usage of mobile phone usage in recent years has dramatically increased our exposure to electromagnetic waves. Standards have been developed for limiting exposure to electromagnetic waves. One of the measures that defines the effect of electromagnetic wave is specific absorption rate(SAR). Specific absorption rate is a measure of the rate of electromagnetic energy absorbed by body tissues or electromagnetic power absorbed by unit tissue. Since calculating SAR with analytical methods is very difficult, numerical methods are preferred. In this study, SAR values were calculated using the Finite Difference Time Domain(FDTD) method. FDTD method, relies on the discretization the partial differential Maxwell equations in space and time using the finite difference approach. FDTD method is used to simulate electromagnetic wave propagation. For the SAR calculation, a 4-layer structure consisting of skin, fat, muscle and bone tissues has been created. Sinusoidal sources with frequencies of 10 MHz and 900 MHz are used. When the wavelength is too large for the tissue thickness, the wave penetrates deeper into the tissue. Within the tissue, the electric field is in close proximity. At 900 MHz the wave penetrates less to the tissues and most of the energy is absorbed in the initial tissues. SAR values within the tissues are given in graphs.

Keywords: Specific Absorption Rate, SAR, Finite Difference Time Domain Method, FDTD

INTRODUCTION

Standards have been developed to decrease the harmful effects of electromagnetic radiation on human health and to enable electromagnetic radiation not to exceed specific values. EM waves are absorbed by tissues of living beings. Some definitions and sizes have been put forward to determine the amount of this absorption.

Specific Absorption (SA)

Specific absorption is the amount of EM energy absorbed by the unit mass of a biological tissue. If the energy absorbed by a very small dm mass is dW, specific absorption is defined as

$$S_A = \frac{dW}{dm} = \frac{dW}{\rho\, dv} \qquad \left(\frac{\text{joule}}{\text{kg}}\right) \tag{1}$$

In equation (1), ρ is the density of the tissue and dv is the differential volume element.

Specific Absorption Rate (SAR)

It is the absorption speed of EM energy absorbed by body tissue or the amount of EM power amount absorbed by a unit of tissue [1] and it is defined as

$$SAR = \frac{dS_A}{dt} \qquad \left(\frac{\text{Watt}}{\text{kg}}\right) \tag{2}$$

From the formulas above, E being the electric field in the body (V/m), σ being body conductivity (mho/m), c being the specific heat capacity of the body (joule/(kg.K)), dT/dt being the change rate of body heat according to time (K0/s) and J being the surface flow density (A/m2), specific absorption rate can be found as

$$SAR = \sigma \frac{|E|^2}{2\rho} = c\frac{dT}{dt} = \frac{||J||^2}{\rho\sigma} \tag{3}$$

According to this, SAR value can be found with three different ways as electric field, heat change speed and flow density. Since heat change and flow density measurements are more difficult, SAR measurements are generally conducted by using electric field. Different definitions have been made for SAR, such as total SAR (SAR_T), average SAR (SAR_A), temporally averaged SAR (SAR_{TA}) and spatial peak SAR(SARpeak). Total SAR is found by adding up the SAR values in all the cells of the matter[2]. Total SAR is

$$SAR_T = \iiint \sigma \frac{|E|^2}{2\rho}\, dx\, dy\, dz \tag{4}$$

Average SAR is the division of total SAR value by the number of cells in the matter. Temporally averaged SAR is the division of SAR values in all time steps by the number of repetitions.

MATERIALS AND METHODS

In this study, SAR values were calculated using the Finite Difference Time Domain(FDTD) method. FDTD method, relies on the discretization the partial differential Maxwell equations in space and time using the finite difference approach. For the SAR calculation, a 4-layer structure consisting of skin, fat, muscle and bone tissues has been created. Sinusoidal sources with frequencies of 10 MHz and 900 MHz are used[3]. Tissue thickness was taken as skin: 0.3 cm, fat: 3.0 cm, muscle: 2.0 cm and bone: 3.0 cm. Table-1 gives parameters of skin, fat, muscle and bone tissues for 10MHz.

Table 1. Skin, fat, muscle and bone tissue parameters at 10 MHz

Tissue	Thickness (cm)	Dielectric	Conductivity	Density
Skin	0.3	361.66	0.19732	1050
Fat	3.0	13.767	0.029152	918
Muscle	2.0	170.73	0.61683	1050
Bone	3.0	36.772	0.042822	1920

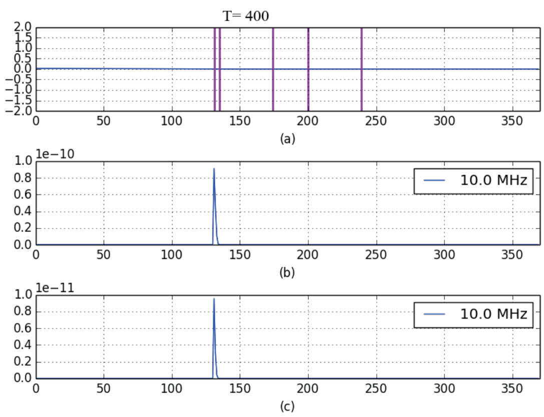


Figure 1. Simulation results for 10 MHz

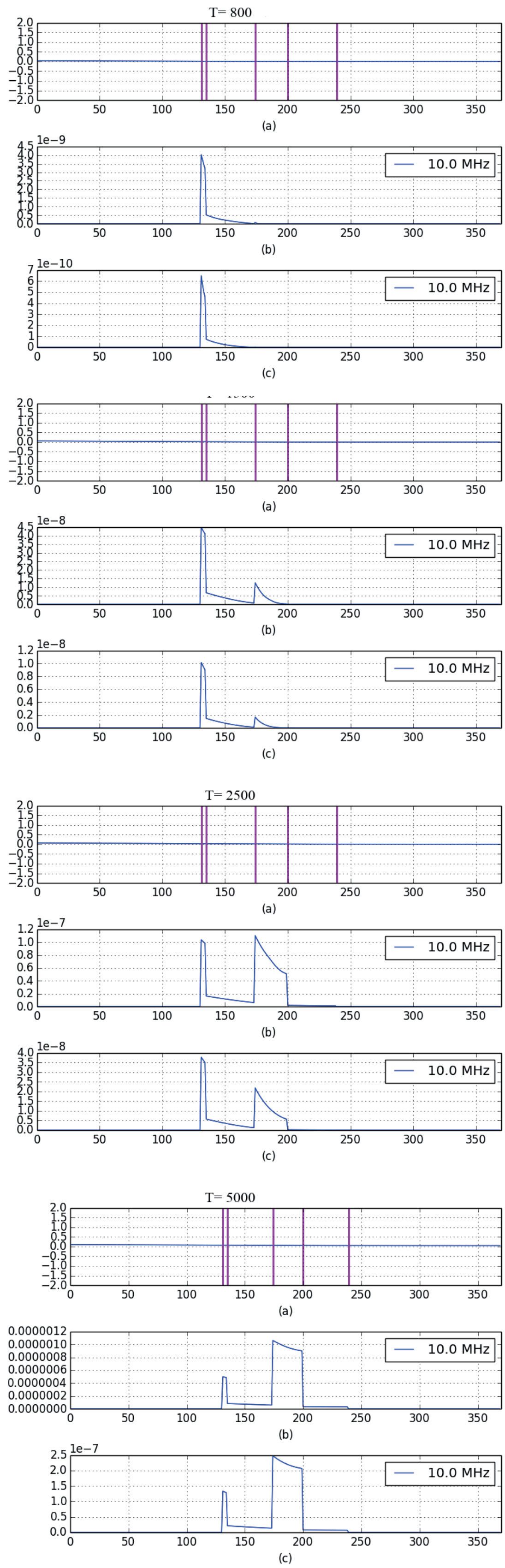


Figure 1. Simulation results for 10 MHz (Continue)

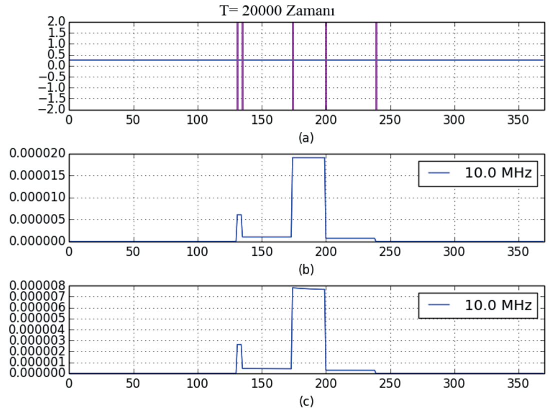


Figure 1. Simulation results for 10 MHz (Continue)

Table-2 gives parameters of skin, fat, muscle and bone tissues for 900MHz.

Table 2. Skin, fat, muscle and bone tissue parameters at 900 MHz

Tissue	Thickness (cm)	Dielectric	Conductivity	Density
Skin	0.3	41.405	0.86674	1050
Fat	3.0	5.462	0.051043	918
Muscle	2.0	55.032	0.94294	1050
Bone	3.0	12.454	0.14331	1920

Fig. 2 shows the SAR values calculated for 900 MHz for different iterations.

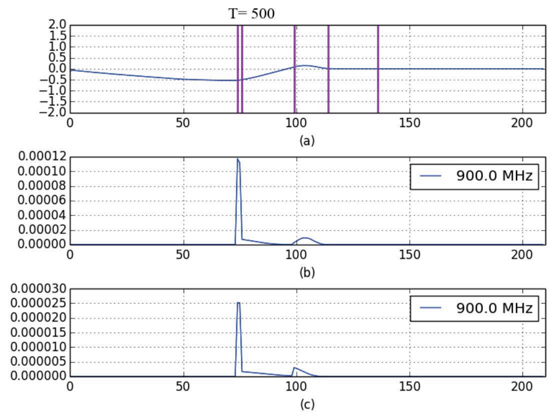
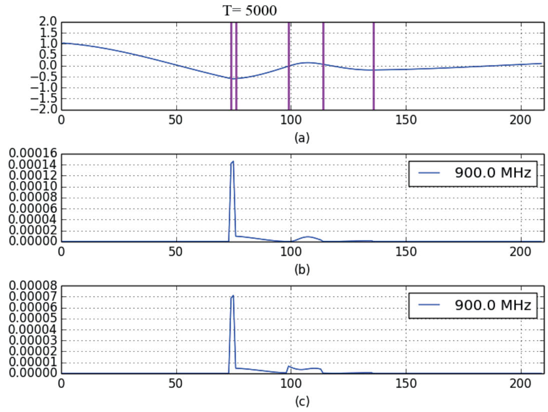
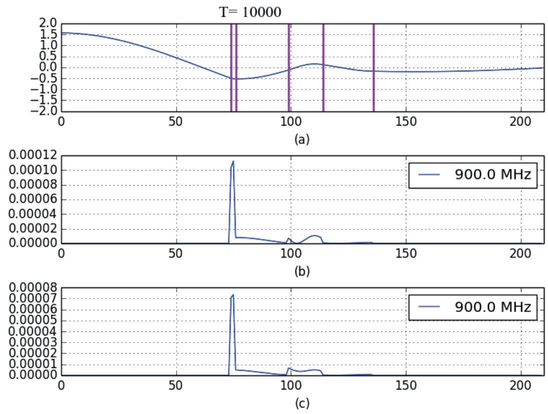


Figure 2. Simulation results for 900 MHz





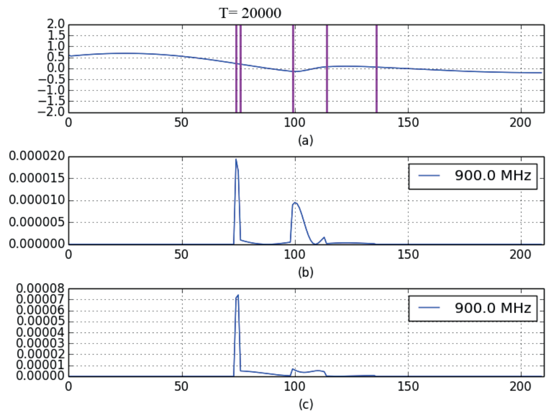


Figure 2. Simulation results for 900 MHz (Continue)

RESULTS AND DISCUSSION

When the graphs are examined, at 10 MHz, sharp rises and falls have been observed between SAR values of the tissues. When the wave length is much higher when compared with tissue thickness, the wave penetrates deeper in the tissue and the electric field in the tissue gets values almost close. For this reason, SAR values depend on conductivity and tissue density. The densities of tissues used in simulation are close to each other except for bones. For this reason, conductivity comes to the forefront in the determination of SAR values. Conductivity is in the form of muscle, skin, bone and fat from the lowest to the highest. For this reason, SAR value is greater in the muscle tissue. Since conductivity is smaller in fat tissue, SAR value is also smaller. Bone tissue density is approximately two times greater than the others and when density is also taken into consideration, it has the smallest SAR value.

At 900 MHz, wave penetrates to tissues less and a great part of the energy is absorbed in first tissues. For this reason, SAR value is higher in the skin. With less reflection in the fat tissue, there also occurs less absorption. Thus, SAR value was found to be low in fat.

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