Biological Effects of Microwave Radiation

Presented By:

Suruchi Kumari
ECE,NIT Trichy

COMSOL
CONFERENCE
2014 BANGALORE

Excerpt from the Proceedings of the 2014 COMSOL Conference in Bangalore

Model

- Desired model is made using Comsol 4.4.
- It consists of RF model and Heat transfer model.
- RF module solves for Electromagnetic field distribution and SAR in Human body.
- Heat Transfer Model solves for temperature increase because of electromagnetic energy absorption. Both model is coupled together through Comsol Multiphysics.

Assumptions made for RF model

- Electromagnetic wave propagation is modeled in two dimensions.
- The human body in which electromagnetic waves interact proceeds in free space.
- The free space is truncated by a scattering boundary condition.
- The model assumes that dielectric properties of each tissue are uniform and constant.

Equation used for RF module

- The electromagnetic wave propagation in a human body is calculated using Maxwell's equations. The general form of Maxwell's equations is simplified to get electromagnetic field penetrated in human body as the following equation:

$$\Delta \times \frac{1}{\mu_r} \Delta \times E \; - \; {k_0}^2 \varepsilon_r E = 0$$

where E is electric field intensity (V/m),μ_r is relative magnetic permeability, $\varepsilon_r$relative dielectric constant, and ko is the free space wave number (m^{-1}).

Equation used for RF module

- The Maxwell's equation demonstrates the electromagnetic field of microwaves penetrated in the human body

$$\Delta \times \left(\frac{1}{\mu_r} \Delta \times E\right) \; - \; {k_0}^2 \left(\varepsilon_r - j \frac{\sigma}{\omega \varepsilon_0}\right) \; E = 0$$

$\varepsilon_r = n^2$ Where n is refractive index

- The perfect-electric-conductor boundary condition along the patches $\mathrm{n} \times \mathrm{E} = 0$
- Continuous boundary conditions along the interfaces of two different mediums, $\mathrm{n} \times (\mathrm{E}_1 - \mathrm{E}_2) = 0$
- The outer sides of free space are considered as scattering boundary conditions to define absorbing boundaries

$$\mathrm{n} \times (\Delta \times \mathrm{E}) - \; \mathrm{jknk} \times (\mathrm{E} \times \mathrm{n}) = -\mathrm{n} \times \left(\mathrm{E}_0 \times \mathrm{jk} \times (\mathrm{n} - \mathrm{k})\right) \mathrm{exp}(-\mathrm{jk.r})$$

Assumptions made for Heat transfer model

- Human tissue is biomaterial with uniform and constant thermal properties.
- There is no energy exchange throughout the human body model.
- There is no chemical reaction within the tissue.

Equation used for Heat Transfer

- The temperature distribution within the human head is obtained by solving Pennes' bio heat equation. The bio heat equation describes effectively how heat transfer occurs within the human body, and the equation is:

$$\frac{\rho C \partial T}{\partial t} = \nabla.(k \nabla T) + \rho_b C_b \, \omega_b (T_b - T) + Q_{met} + Q_{ext}$$

Where ρ = tissue density (kg/m^3)
C =heat capacity of tissue (J/kg K)
k = thermal conductivity of tissue (W/m K)
T=tissue temperature (C)
T_b = temperature of blood (C)
ρ_b =density of blood (kg/m^3),
C_b = heat capacity of blood(3960 J/kg K)
ω_b =blood perfusion rate (1/s)
Q_{met}=metabolism heat source (W/m^3)
Q_{ext} = external heat source(W/m^3).

Equation used for heat transfer

- The boundaries of the human body are considered as an insulated $n.(k\nabla T) = 0$
- The internal boundaries of human body are assumed as continuous boundaries $n.(k_1\nabla T_1 - k_2\nabla T_2) = 0$

For this analysis, the temperature distribution within the human body is assumed to be uniform. Initial temperature of the human body is defined as $T(t_0)$ = 37 °C .The thermoregulation mechanisms and the metabolic heat generation of each tissue is neglected

$Q_{met}=0$.

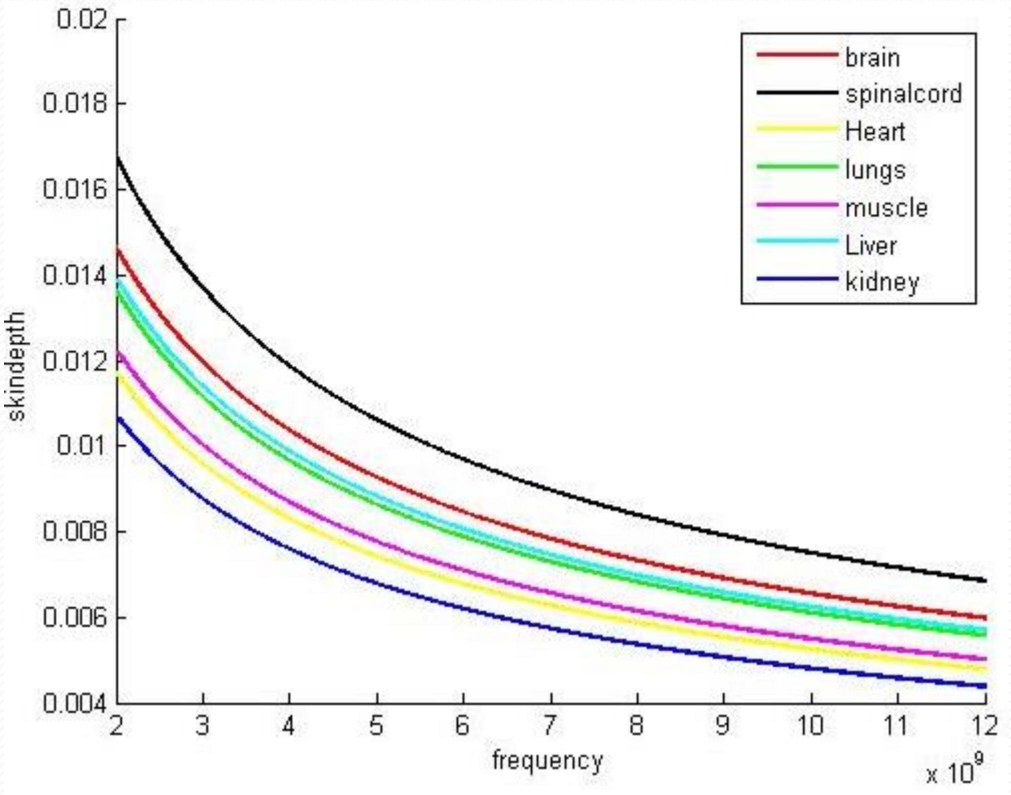
Electric data of Biological Tissue

Electrical data	value
epsilonr_substrate	5.23
epsilonro_brain	49.7
sigmao_brain	0.59[S/m]
rho_brain	1.04e3[kg/m^3]
c_blood(Heat capacity of blood)	3639[J/(kg*K)]
dens_liver	1050
rho_blood	1000[kg/m^3]
eps_skin	46.7
eps_heart	66
dens_skin	1010
eps_liver	51.2
eps_kidney	66.4
cond_skin	0.69
cond_heart	0.97
cond_liver	0.65
cond_kidney	1.10
dens_heart	1050[kg/m^3]
dens_kidney	1050[kg/m^3]

Skin depth

- $\varepsilon_r = \varepsilon_r{}' - j\varepsilon_r{}''$
- $\varepsilon_r{}' = \frac{\varepsilon_{r0}-\varepsilon_{r\infty}}{1+\omega^2\tau^2} + \varepsilon_{r\infty}$ $\varepsilon_r{}'' = \frac{(\varepsilon_{r0}-\varepsilon_{r\infty})\omega\tau}{1+\omega^2\tau^2}$
- $\delta_e = \frac{1}{\omega}\left(\frac{\mu\varepsilon}{2}\right)\left\{\left[\left(1+\left(\frac{\sigma}{\omega\varepsilon}\right)^2\right)^{\frac{1}{2}}\right]-1\right\}^{\frac{1}{2}}$

Skin depth



0.02
0.018
0.016
0.014
0.012
0.01
0.008
0.006
0.004
skindepth
2
3
4
5
6
7
8
9
10
11
12
frequency
x 10^9
brain
spinalcord
Heart
lungs
muscle
Liver
kidney

SAR

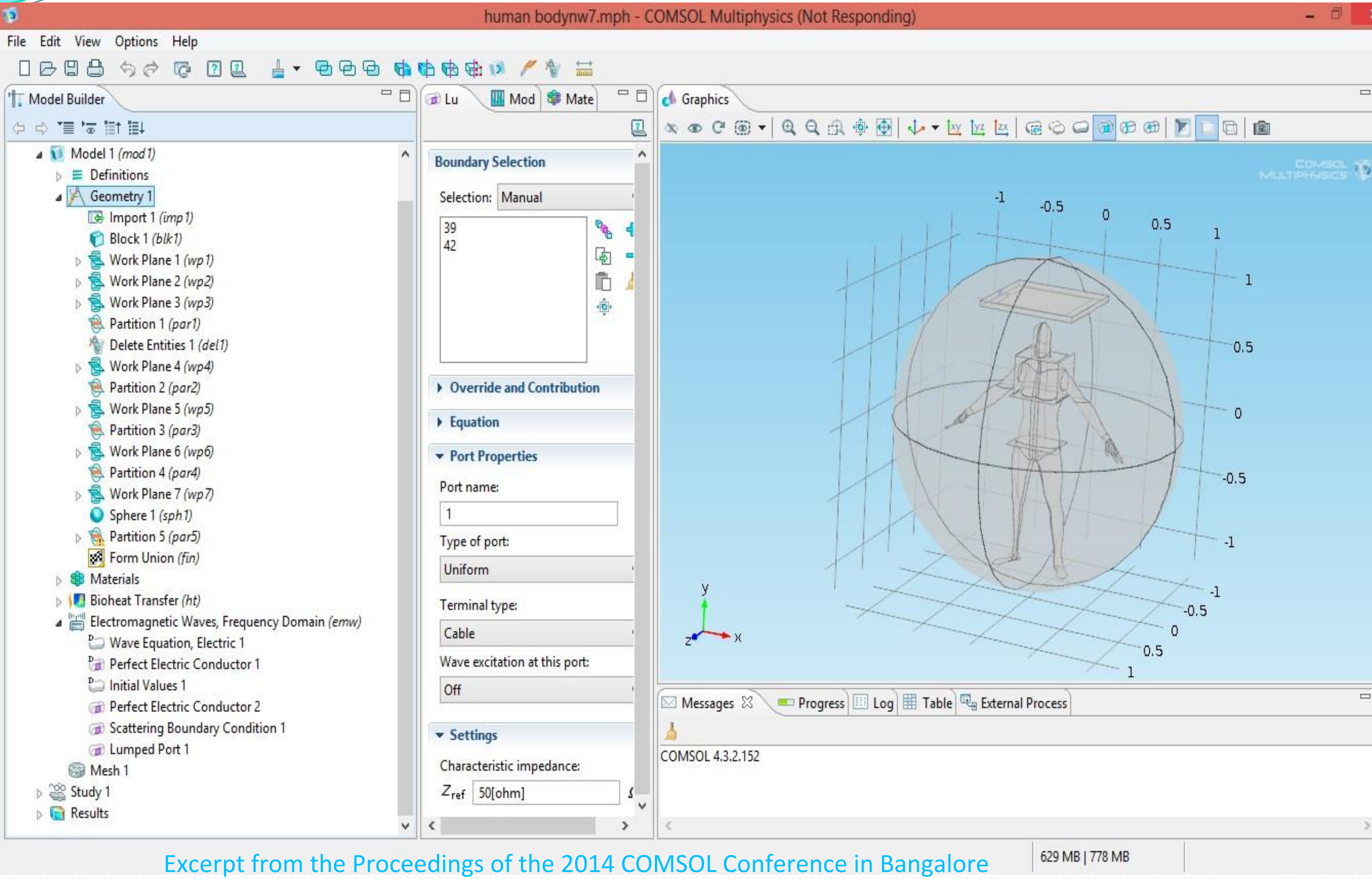
- Human tissues are lossy mediums with finite electric conductivity for EM waves. They are neither good dielectric materials nor good conductors, hence when EM waves propagate through the human tissues is absorbed by the human tissues. It is represented by Specific absorption rate.
- The specific absorption rate is given by equation SAR= $\frac{\sigma|E(r)|^2}{2\rho}$

Where E(r) is the electric field intensity at a distance r, σ is the conductivity of human brain tissue, ρ is the density.

Steps of Work done in COMSOL

- Geometry
- Partitioning of Geometry
- Material Assignment to different domains
- Added physics.
- Addition of RF and Heat transfer module
- Addition of all equations and Boundary condition of these models.
- Meshing
- Computation
- Analysis of Result.

Model Structure



- Model 1 *(mod1)*
  - Definitions
  - Geometry 1
    - Import 1 *(imp1)*
    - Block 1 *(blk1)*
    - Work Plane 1 *(wp1)*
    - Work Plane 2 *(wp2)*
    - Work Plane 3 *(wp3)*
    - Partition 1 *(par1)*
    - Delete Entities 1 *(del1)*
    - Work Plane 4 *(wp4)*
    - Partition 2 *(par2)*
    - Work Plane 5 *(wp5)*
    - Partition 3 *(par3)*
    - Work Plane 6 *(wp6)*
    - Partition 4 *(par4)*
    - Work Plane 7 *(wp7)*
    - Sphere 1 *(sph1)*
    - Partition 5 *(par5)*
    - Form Union *(fin)*
  - Materials
  - Bioheat Transfer *(ht)*
  - Electromagnetic Waves, Frequency Domain *(emw)*
    - Wave Equation, Electric 1
    - Perfect Electric Conductor 1
    - Initial Values 1
    - Perfect Electric Conductor 2
    - Scattering Boundary Condition 1
    - Lumped Port 1
  - Mesh 1
- Study 1
- Results

Boundary Selection

Selection: Manual

39
42

Override and Contribution

Equation

Port Properties

Port name: 1

Type of port: Uniform

Terminal type: Cable

Wave excitation at this port: Off

Settings

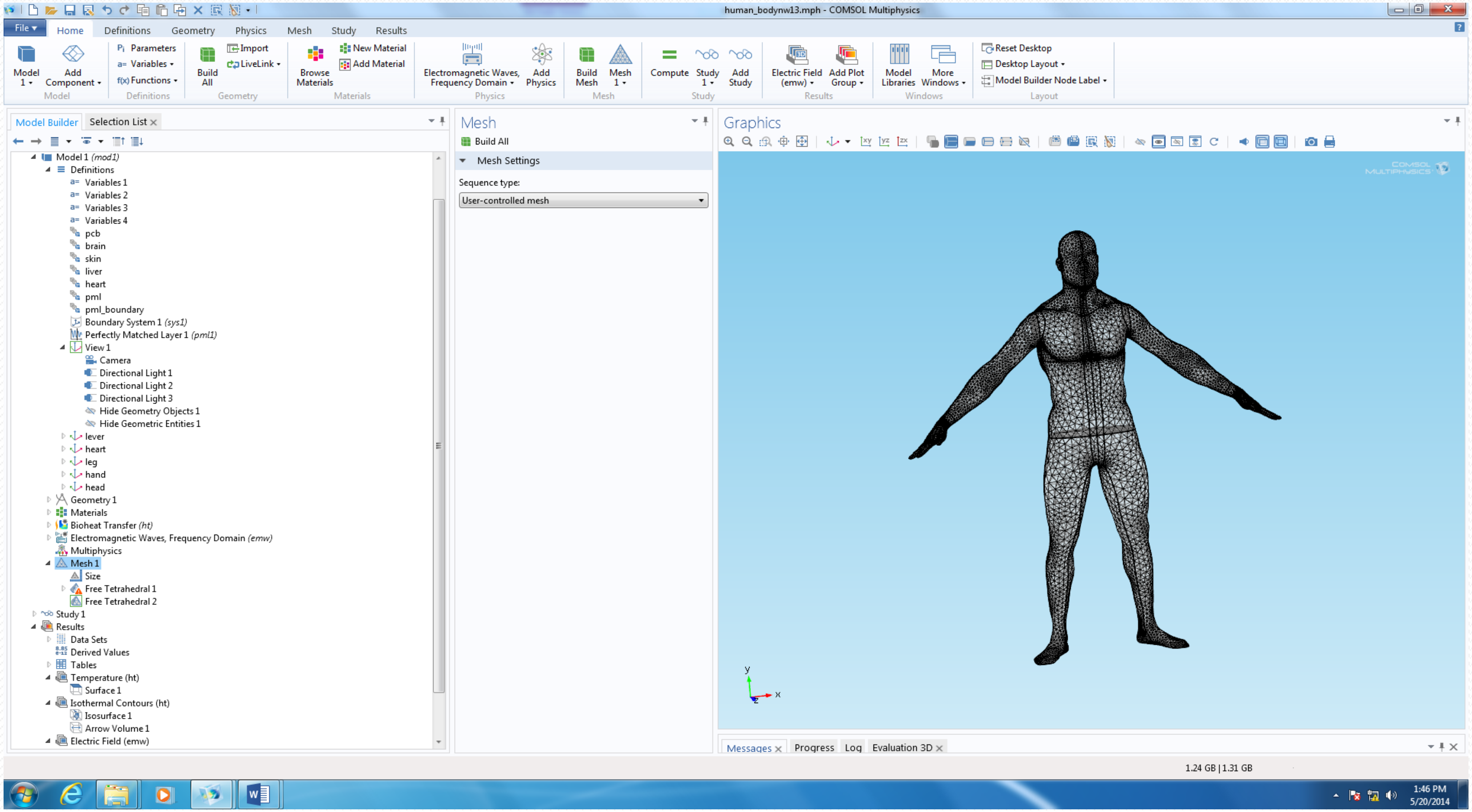
Characteristic impedance:

Z_{ref} 50[ohm]

COMSOL 4.3.2.152

629 MB | 778 MB

Meshing of Humam body

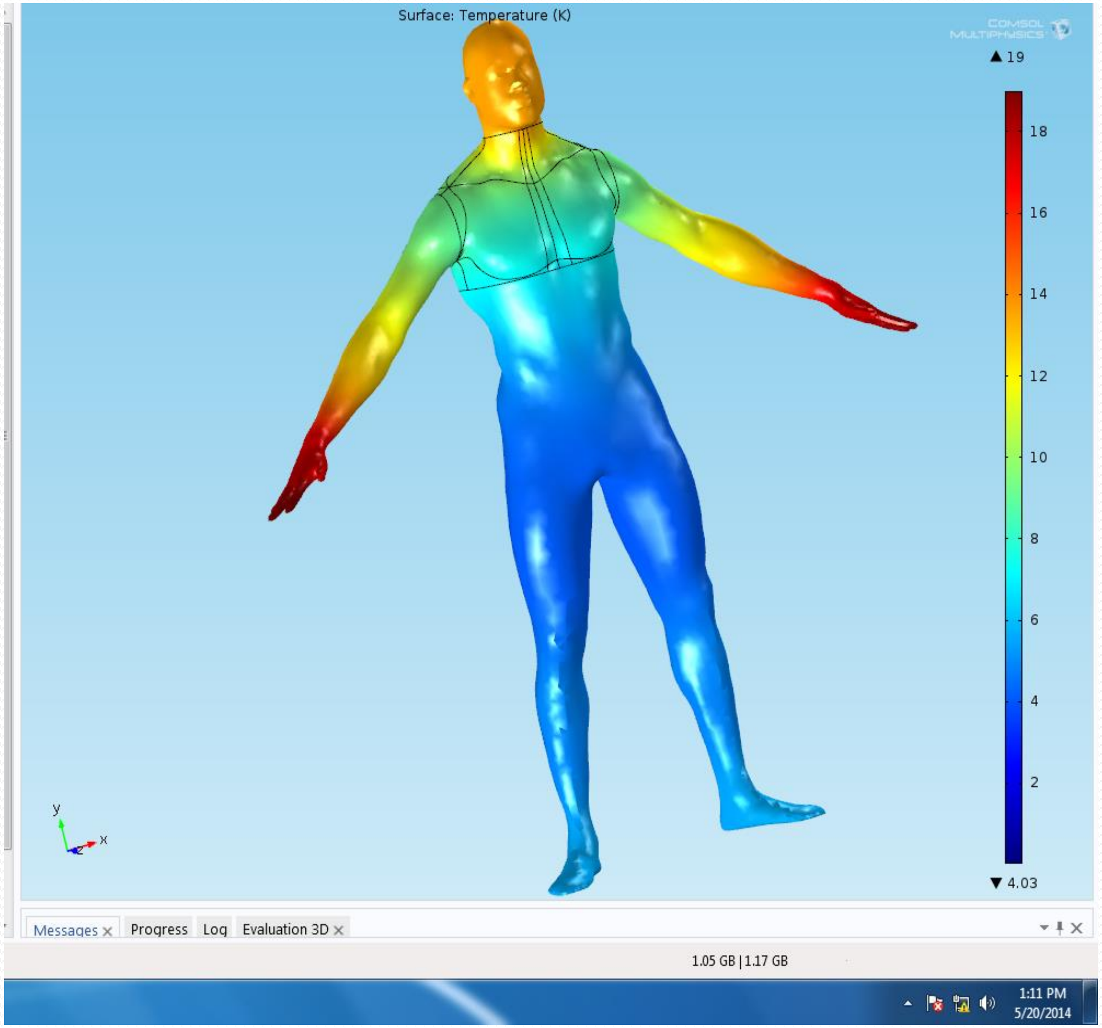


- Model 1 (mod1)
  - Definitions
    - Variables 1
    - Variables 2
    - Variables 3
    - Variables 4
    - pcb
    - brain
    - skin
    - liver
    - heart
    - pml
    - pml_boundary
    - Boundary System 1 (sys1)
    - Perfectly Matched Layer 1 (pml1)
    - View 1
      - Camera
      - Directional Light 1
      - Directional Light 2
      - Directional Light 3
      - Hide Geometry Objects 1
      - Hide Geometric Entities 1
    - lever
    - heart
    - leg
    - hand
    - head
  - Geometry 1
  - Materials
  - Bioheat Transfer (ht)
  - Electromagnetic Waves, Frequency Domain (emw)
  - Multiphysics
  - Mesh 1
    - Size
    - Free Tetrahedral 1
    - Free Tetrahedral 2
- Study 1
- Results
  - Data Sets
  - Derived Values
  - Tables
  - Temperature (ht)
    - Surface 1
  - Isothermal Contours (ht)
    - Isosurface 1
    - Arrow Volume 1
  - Electric Field (emw)

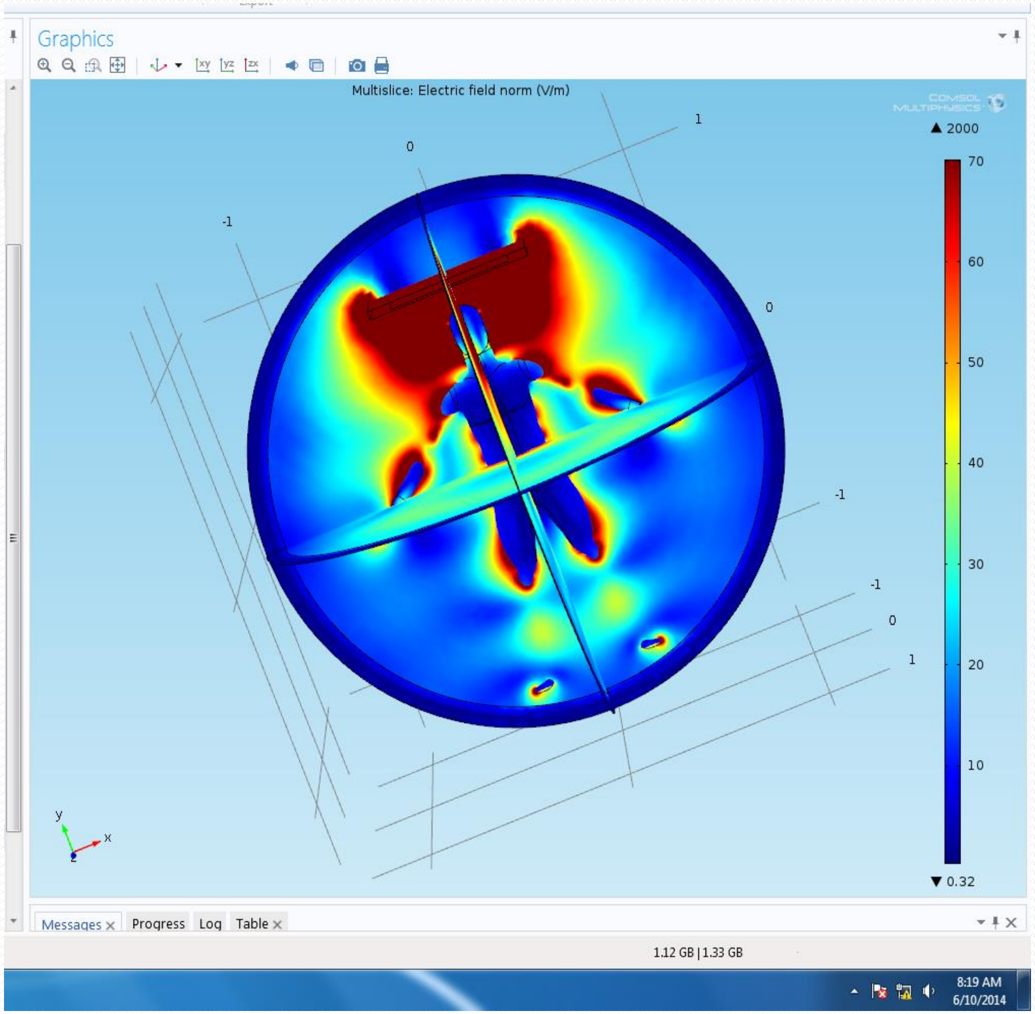
Mesh Settings

Sequence type: User-controlled mesh

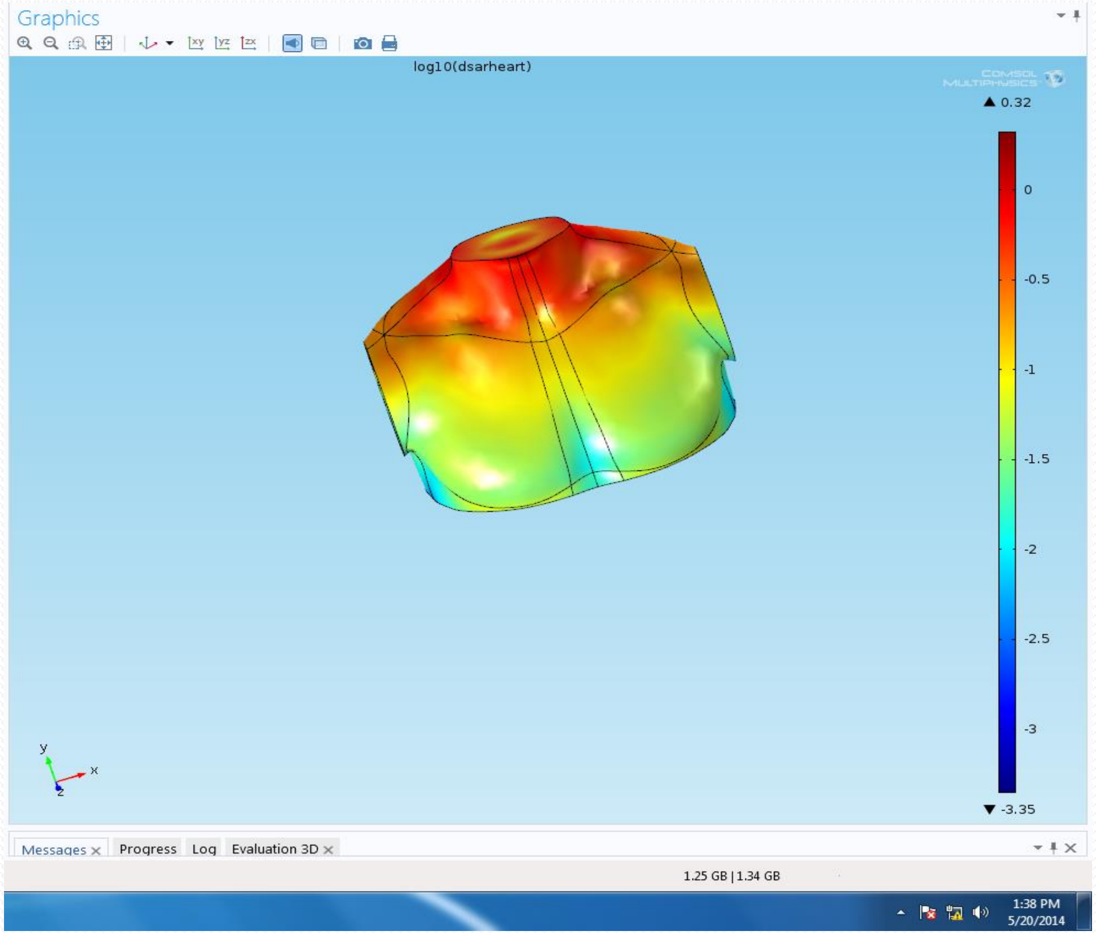
Temperature increased in human body



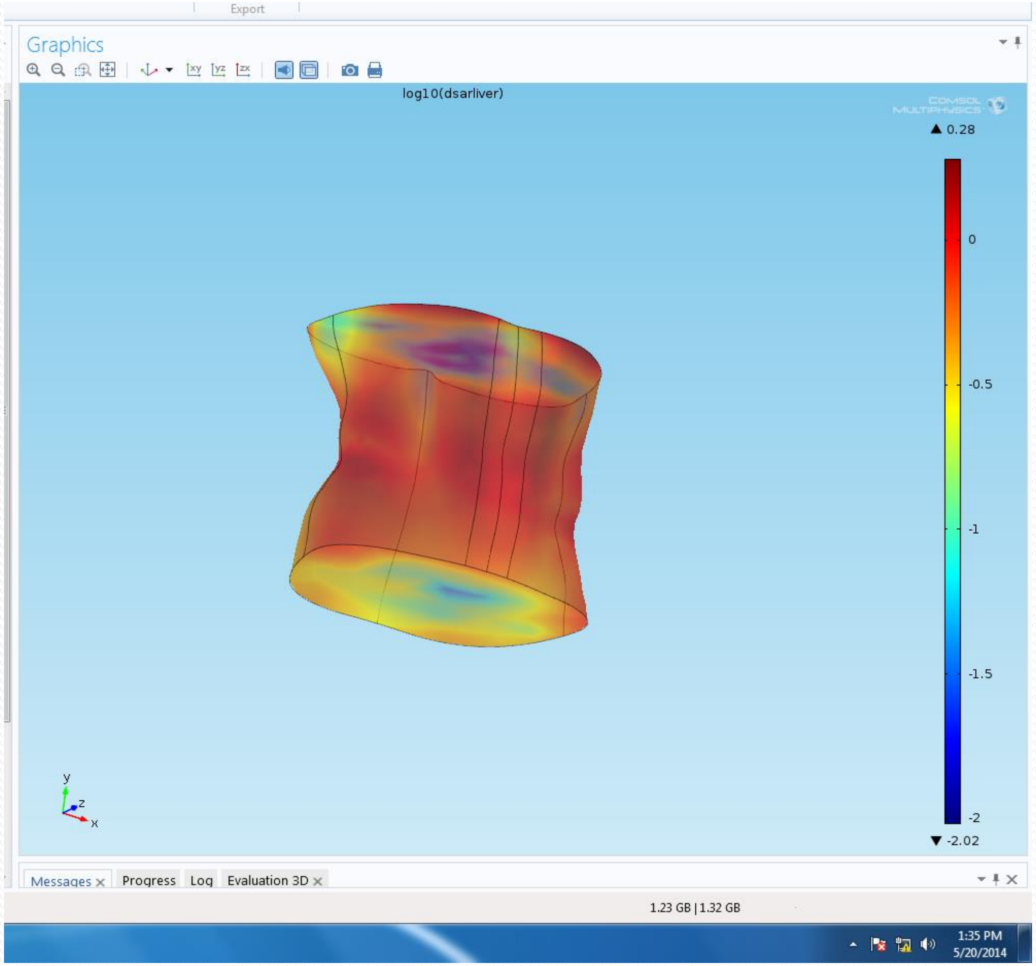
Electric Field in human body



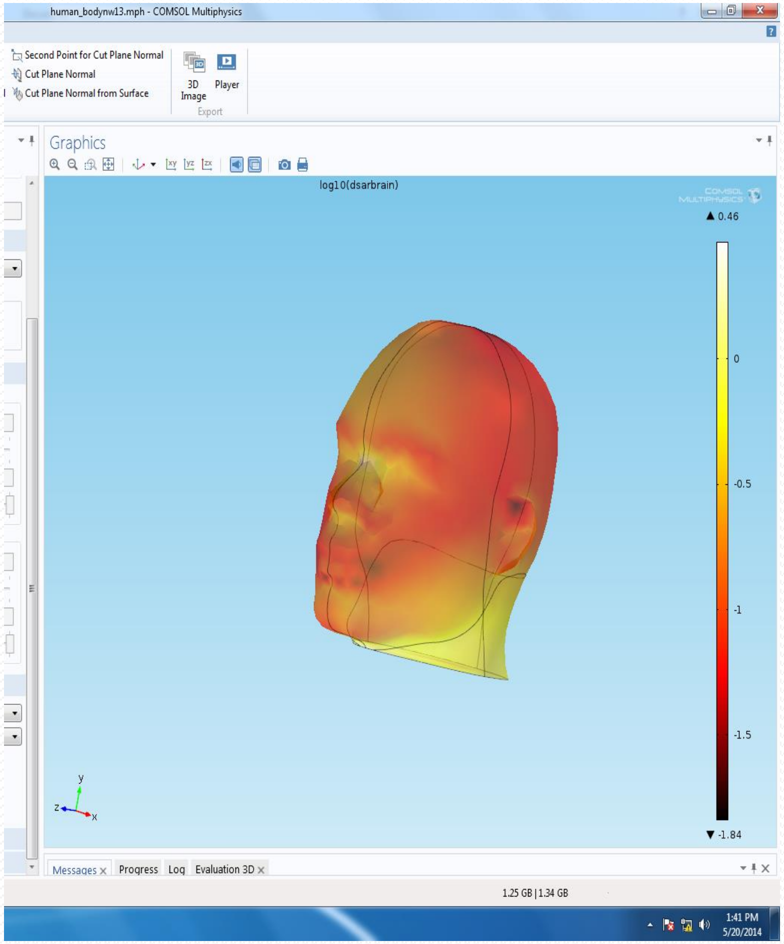
SAR in human heart



SAR in human lever



SAR in Human Brain



Conclusion

The biological effects of EM radiation are studied by observing the variations in temperature and SAR on human body due to cell phone radiations.

The study gives solid evidences of the adverse effects the radiations causes in a human body . These results can be taken as a reference for better design of EM emitting devices and also for treatment of illness related to these radiations.

References

[1] André Vander Vorst, Arye Rosen, Youji Kotsuka, *RF/Microwave Interaction with Biological Tissues*. Hoboken, New Jersey: A John Wiley & Sons, Inc., 2006.

[2] M. Okoniewski, M. A. Stuchly, "A study of the handset antenna and human body interaction," in A. Rosen and A. Vander Vorst (Eds.), Special Issue on Medical Application and Biological Effects of RF/Microwaves, *IEEE Trans. Microwave Theory Tech*.,Vol. 44, No. 10, pp. 1855–1864, Oct. 1996.

[3] S. Michaelson, J. C. Lin, *Biological Effects and Health Implications of Radiofrequency Radiation*, New York: Plenum, 1987.

[4] H. G. Booker, *Energy in Electromagnetism*, Stevenage: P. Peregrinus, 1982.

[5] S. M. Michaelson, J. C. Lin, *Biological Effects and Health Implications of Radiofrequency Radiation*, New York: Plenum, 1987.

[6] J.Thuery, *Microwaves: Industrial, Scientific and Medical Applications*, Boston,MA:Artech House, 1992.

References

[7] G. Grosse, “Permittivity of a suspension of charged spherical particles in electrolyte solution. II. Influence of the surface conductivity and asymmetry of the electrolyte on the low and high frequency relaxations,” J. Phys. Chem.,Vol. 92, pp. 3905–3910, 1988.

[8] G. Grosse, K. R. Foster, “Permittivity of a suspension of charged spherical particles in electrolyte solution,” J. Phys. Chem.,Vol. 91, p. 3073, 1987.

[9] K. R. Foster, H. P. Schwan, “Dielectric properties of tissues,” in C. Polk and E. Postow (Eds.), Handbook of Biological Effects of Electromagnetic Fields, Boca Raton, FL: CRC Press, 1996.

[10] Girish Kumar, “Cell Tower Radiation,” Mumbai, December 2010.

THANK YOU