Temperature variations within a multi-layered skin tissue exposed to the 5G mobile communications frequency radiation

Jagbir Kaur [1*], Suyeb Ahmed Khan[2]

[1]Department of Research and Development,I.K. Gujral Punjab Technical University, Kapurthala, India- 144603
[2]Department of Electronics and Communication Enggineering, Baba Kuma Singh Ji College of Engg., Amritsar, India – 143107

*Corresponding author
doi: https://doi.org/10.21467/proceedings.114.26

Abstract

The 5G mobile communication systems are the "next generation" communication systems. They are capable of providing numerous benefits to the mobile phone users. But whether they are safe to use is still a topic of concern. This study investigates the thermal safety of 5G mobile phone frequency. A three-dimensional multi-layered skin tissue is exposed to 60 GHz frequency from a mobile patch antenna. The simulation software COMSOL Multiphysics is employed to map the electric field distribution and the temperature distribution within the exposed domain. The peak temperature (37.36°C) is estimated in the subcutaneous fat layer of the skin tissue. The temperature peak is very short lived and the steady state temperature is same as the core body temperature. The results suggest that the temperature rise caused by the 5G mobile phone radiation exposure is not capable of causing the thermal burns in the exposed tissue. Therefore, the 5G mobile communication frequency of 60 GHz can be considered "thermally" safe.

Keywords: 5G frequency, mmWs, Penne's bioheat model, electric field, mobile phone radiation

1 Introduction

The mobile communication system is all set for the advent of the 5G system. This "next generation" system has the potential to address the increasing demand of seamless connectivity. As the sub 3GHz frequency range is becoming over crowded, the millimeter wave (mmW) frequencies (30-300 GHz) are the favorite candidate for 5G communication systems, since they may provide huge amount of raw bandwidth and multigigabit-per-second (Gb/s) data rates [1]. Although 5G mobile system has numerous benefits, there is a concern about their biological safety among the scientists as well as the public. Since the mmWs have very small wavelength, their penetration inside the biological medium is shallow. Therefore, when these radiation irradiate the human body, their penetration is limited to the skin layer of the exposed tissue. The electromagnetic (EM) energy associated with the mmWs is absorbed by the exposed tissue, which causes the ion acceleration and collisions among the molecules. As the result, the local temperature of exposed tissue increases. The reports have shown that a minor temperature change of 1-5°C in the tissue may interfere with the functioning of the organs [2,3].

In the present study, we investigated the temperature variations within a three-dimensional (3D) multilayered skin tissue exposed to 60 GHz mobile phone radiation. The study is done on the skin tissue model because the mobile phone users keep their phones near to the skin surface, therefore, the thermal variations are more likely to occur in the skin layer [4]. A 3D model of skin is used in the analysis since a simulation which employs a 3D model, provides the results that approaches the reality more accurately[5,6]. The 60 GHz frequency is the promising choice for the 5G mobile communications [7]. The 3D skin tissue model is irradiated by the mmWs from a microstrip antenna of a mobile phone. The output power radiated

© 2021 Copyright held by the author(s). Published by AIJR Publisher in the "Proceedings of International Conference on Women Researchers in Electronics and Computing" (WREC 2021) April 22–24, 2021. Organized by the Department of Electronics and Communication Engineering, Dr. B. R. Ambedkar National Institute of Technology, Jalandhar, Punjab, INDIA
Proceedings DOI: 10.21467/proceedings.114; Series: AIJR Proceedings; ISSN: 2582-3922; ISBN: 978-81-947843-8-8

by the half wave dipole microstrip antenna is in compliance with the ICNIRP's power density limit of 10 W/m² [8]. The obtained temperature variations confirm the thermal safety of the 5G mobile phones.

2 Methods

A 3D skin model containing four different layers, viz. epidermis, dermis, subcutaneous fat, and inner tissue (muscle) is exposed to 5G mobile communication frequency of 60 GHz (Fig.1). The mobile phone patch antenna is placed at a distance of 2 cm from the exposed surface of the skin model. The EM energy is emitted by the lumped port of the patch and this energy is absorbed by the skin tissue. Table I and Table II list the physical and dielectric properties of various skin layers, respectively.

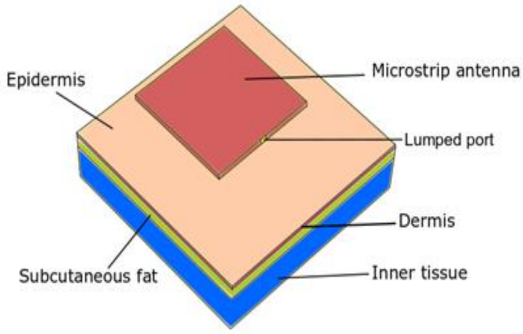

Figure 1. Schematic geometry of multilayered skin tissue model with microstrip patch antenna.

PHYSICAL AND THERMAL PROPERTIES OF SKIN LAYERS [9]

Tissue	**Specific Heat, C_p (J/kg. K)**	**Thermal conductivity, K (W/m.K)**	**Mass density, ϱ (kg/m³)**	**Perfusion rate, ω (1/s)**	**Thickness, x (m)**
Epidermis	3600	0.235	1190	0	80*10E-6
Dermis	3300	0.445	1116	1.5	0.002
Subcutaneous Fat	2700	0.185	971	1.5	0.01
Inner tissue (muscle)	4000	0.5	1,000	1.5	0.03

TABLE II. DIELECTRIC PROPERTIES OF SKIN LAYERS AT 60 GHZ [10]

Tissue	**Permittivity ε_r**	**Conductivity σ (S/m)**
Epidermis	3.32	1.78
Dermis	4.15	25.6
Subcutaneous fat	3.67	10.95
Inner tissue (muscle)	12.9	52.8

We have employed COMSOL Multiphysics® software to numerically analyze the electric field and temperature variations within the exposed tissue. The investigation is executed in two steps: (a) electromagnetic analysis and (b) bioheat analysis. In the electromagnetic analysis, the electric field is determined, and the thermal changes are evaluated in the bioheat analysis.

2.1 Electromagnetic Analysis

The propagation of electromagnetic waves inside a biological medium is governed by the Maxwell's equations. The electric field (E) generated inside the tissue can be determined using the equation [11]:

$$\nabla \times \frac{1}{\mu_r}(\nabla \times E) - k_0^2(\varepsilon_r - \frac{j\sigma}{\omega\varepsilon_0})E = 0 \quad (1)$$

where μ_r is the relative magnetic permeability, ε_r is relative permittivity, ε_0 = 8.8542×10^{-12} F/m, k_0 is the free space wave number, σ is conductivity of tissue and ω is angular frequency.

2.2 Bioheat Analysis

We have employed the Penne's bioheat transfer model to predict the temperature changes within the skin tissue exposed to the 5G mobile phone radiation. The mathematical equation for Penne's bioheat model is [12]:

$$\rho C_p \frac{\partial T}{\partial t} = \nabla.(K\nabla T) + \rho_b C_{p,b}\omega_b(T_b - T) + Q_m + Q_{ext} \quad (2)$$

where ρ, C_p and K are the density, specific heat at constant pressure, and the thermal conductivity of tissue, respectively. ρ_b and $C_{p,b}$ are the density and specific heat (at constant pressure) of the blood, respectively. ω_b is the blood perfusion rate; T and T_b are the tissue and blood temperatures, respectively. Q_m is metabolic heat generation in the tissue, since we aim to estimate the temperature changes caused by the mobile phone radiation, therefore, we have ignored the metabolic heat generation. Q_{ext} is the resistive heat generated by the exposure to the electromagnetic source and is expressed as [11,13]:

$$Q_{ext} = \frac{1}{2}\sigma|E|^2 \quad (3)$$

The Initial temperature of the skin tissue is 34°C and the blood temperature is same as the core body temperature i.e. 37°C.

3 Results

3.1 Electric Field Distribution

Fig. 2 shows the steady state electric field distribution in the skin tissue exposed to the radiation emitted by the 5G mobile phone antenna. The maximum value of the electric field, V(max) is 550.70 V/m. It is observed that the highest value of the electric field is estimated just in the vicinity of the lumped port. The electric field pattern is not scatterd, but the hotspots are created. This conveys that the electromagnetic energy distribution is confined only to a narrow region.

3.2 Temperature Distribution

Fig. 3 demonstrates the temperature distribution within the exposed skin tissue model at varioius instances of the mmW exposure. The initial temperature of the skin tissue is 34°C, and core body temperature is 37°C. The tissue responds immediately to the mmW exposure and the temperature rises quickly. The peak temperature is observed at 2 s of exposure. The highest temperature estimated is 37.36°C in the subcutaneous fat layer of the exposed tissue. The reason for the occurance of peak temperature in fat layer may be the low thermal conductivity of this layer (Table I). The temperature peak is very short lived and the temperature falls quickly, at 10 s of exposure, the temperature approaches the core body temperature i.e. 37°C.

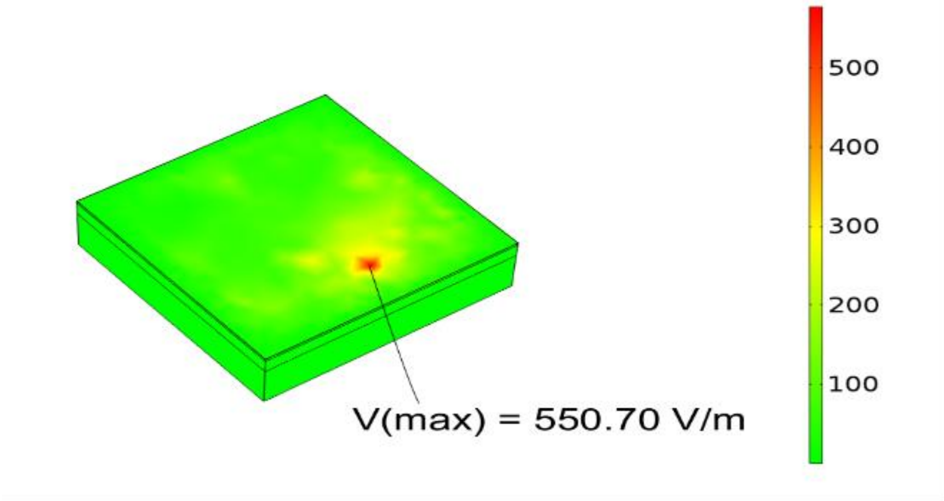

Fig 2. Steady state electric field distribution in skin tissue at 60 GHz.

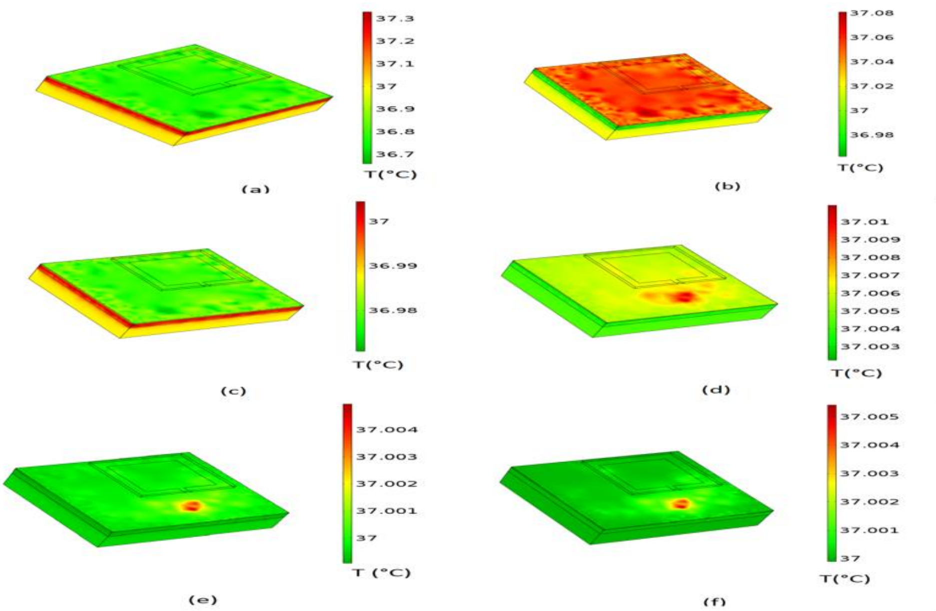

Fig. 3. Temperature distribution within the exposed skin tissue at various instances of exposure (a) 2 s (b) 10 s (c) 30 s (d) 60 s (e) 300 s (f) 600 s

The onset of blood perfusion can be held responsible for this sharp decrease in the temperature. The flow of the blood sweeps the heat energy accumulated in the tissue away from the exposed region and temperature of the exposed tissue decreases. After this stage, only trivial changes in the temperature occur and the temperature is maintained around the core body temperature. The highest steady state temperature is 37.006°C which is not higher enough to cause any thermal injury to the exposed tissue.

4 Conclusions

This study investigates the thermal variations in a three dimensional multi-layered skin tissue that has been exposed the mmWs from a 5G mobile phone patch antenna. The study shows that the highest temperature (37.36°C) is estimated in the fat layer of the skin tissue, and the temperature peak is short lived. The steady state temperature is almost same as the core body temperature. It can be cocluded from the analysis that temperature rise caused by the mmW exposure is not capable of causing the thermal burns in the exposed tissue. Therefore, the 5G mobile communication frequency of 60 GHz can be considered "thermally" safe. However, more studies are needed to confirm the biological safety of these radiation

References

[1] W. Xiang, K. Zheng, and X. Shen, 5G Mobile communications. Switzerland: Springer, 2017.

[2] L.J. Challis, Mechanisms for interaction between RF fields and biological tissue.Bioelectromagnetics, 2005, Suppl 7, S98–S106.

[3] M.A. Stuchly, Health effects of exposure to electromagnetic fields. 1995 IEEE Aerospace Applications Conference. Proceedings, 1995, vol. 1, pp. 351–368.

[4] S. Ozen, S. Helhel, & S. Bilgin, Temperature and Burn Injury Prediction of Human Skin Exposed to Microwaves: A Model Analysis, Radiation and Environmental Biophysics, 2011, vol. 50(3), pp. 483–489.

[5] T. Wessapan, & P, Rattanadecho, Specific Absorption Rate and Temperature Increase in the Human Eye Due To Electromagnetic Fields Exposure at Different Frequencies, International Journal of Heat and Mass Transfer, 2013, vol. 64, pp. 426–435.

[6] T. Wessapan, S. Srisawatdhisukul, P. Rattanadecho, Specific Absorption Rate and Temperature Distributions in Human Head Subjected to Mobile Phone Radiation at Different Frequencies, Int. J. Heat Mass Transfer, 2012, vol. 55, pp. 347–359.

[7] T.S. Rappaport et al., Millimeter wave mobile communications for 5G cellular: it will work!. IEEE Access,2013, vol. 1, pp. 235-49.

[8] B. Thors, D. Colombi, Z. Ying, T. Bolin, C. Törnevik, Exposure to RF emf from array antennas in 5G mobile communication equipment. IEEE Access,2016, vol. 4, pp. 7469-7478.

[9] F. Xu, K.A. Seffen, T.J. Lu, Non-Fourier analysis of skin biothermomechanics.International Journal of Heat and Mass Transfer, 2008, vol. 51(9–10), pp.2237-2259.

[10] M. Ney, and I. Abdulhalim, Modeling of reflectometric and ellipsometric spectra from the skin in the terahertz and submillimeter waves region. Journal of Biomedical Optics, 2011, vol. 16(6), pp. 067006-1-15.

[11] J. Kaur and S.A. Khan, Thermal changes in human abdomen Exposed to microwaves: A model study, Advanced Electromagnetics, 2019, vol. 8(3), pp. 65-75.

[12] H.H. Pennes, Analysis of Tissue and Arterial Blood Temperature in the Resting Human Forearm, Journal of Applied Physiology, 1948, vol. 1, pp. 93–122.

[13] T. Wessapan, and P. Rattanadecho, Numerical Analysis of Specific Absorption Rate and Heat Transfer in Human Head Subjected to Mobile Phone Radiation: Effects of User Age and Radiated Power, Journal of Heat Transfer, 2012, vol. 134(12), pp. 121101.