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Induced Field and Thermal Change in Tissues Due to Vertically Earthed Dipole Antenna

By

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Abstract

A numerical computation of the rate of temperature change at different frequencies in different biological tissues is analysed. The induced electric field within the tissues and thereafter specific absorption rate (SAR) are calculated and studied. Then the corresponding rate of temperature change in various tissues at the corresponding microwave frequencies is then assessed. This change in temperature can heat the tissues with passes of time. As this change of temperature in different tissues can be limited by the thermoregulatory system of the biological body at some extent but the minimum distance of the transmitters from the crowded area must be recommended and should be followed strictly.

Keywords: Thermoregulatory System, Specific absorption rate, Field electrically induced, Rate of temperature change

1. Introduction

Modern societies' dependency on technology has expanded humans' exposure to microwave and millimetre waves in all spheres of life. Examples include cutting-edge medical diagnostic and treatment technology, wireless communication innovations, and high power material processing equipment.

Numerous studies have been conducted throughout the years on the potential health effects of exposure to electromagnetic energy at RF/MW frequencies. Numerous studies in the scientific literature [2, [3,] [9], and [13] describe the thermal effect and SAR distribution in biological objects caused by RF/MW radiation from various sources using various approaches, models, and frequencies. W. Joseph et al. [23] evaluated the 4th generation LTE [26] fields, as well as the SAR values from individual exposure metres for numerous human spheroid phantoms. J. Wilen [11] analyzed the exposure of electromagnetic fields near electrosurgical units and MRI-induced temperature change & SAR distribution in phantoms were also evaluated by S. Oh et.al [21].

Exposure to microwave frequency from high power transmitter produces perceptible increase in tissue temperature. The need to establish the upper and lower limits of acceptable exposure to thermal hazards is expanding as the usage of microwave energy, frequently at high power levels, expands. The frequency, intensity, and length of exposure time to RF radiation all affect for how much energy is absorbed by an organism. Radiation causes warmth in living tissue when the rate of energy absorption is very high [22]. Frequently described by authors is the perceived danger posed by mobile phones and cell towers in residential areas[10].

Joseph and Martens [25] and Sirav and Seyhan [4] have already researched the effects of exposure to TV and radio transmitters. P.P. Pathak et al. [17], [23] measured the rate of temperature change in tissues using high frequency TV transmitters as a point source of radiation, although most high-power TV transmitters use dipole antenna that have a finite length.

In this work, there is a numerical computation of rate of change of temperature in different biological tissues exposed to microwave radiation emitted from TV transmitters of 20 kW at distance of 100 m and having a finite length, running for transmission of DD National and NEWS channel at different frequencies in various cities of India. In this paper induced electric field, specific absorption rate and temperature change at different microwave frequencies is calculated.

The process makes use of the following:

i. propagation from the transmitter where the value of the field decreases inversely with distance.
ii. penetration into the human body, where the field diminishes exponentially with depth.
i. SAR is a primary dosimetric characteristic of electromagnetic wave exposure, is proportional to conductivity, the square of the field strength, as well as the inverse of material density and
ii. increase in temperature, that rises with SAR and falls inversely with body material specific heat.

Our thermoregulatory system can limit the change in temperature in different tissues at some extent, but a long exposure can adversely affect the tissues. Most of the cities in the world are not following any guidelines for the installation of these transmitters. This is the only reason that the atmosphere is overflowing with electromagnetic fields, and we are living in the ocean of these fields. High intensity fields exist near the TV/radio/microwave transmitter (including mobile phone towers) may affect people living near these towers. Hence bio-thermal effects of the electromagnetic fields must be evaluated, and guidelines be formulated for installation of transmission towers.

2. Theoretical Consideration

When an alternating electric field E_{rms} is enforced to the human body, an induced field E_i at a given depth z is created.

$$E_i = E_{rms} exp\left(\frac{-z}{\delta}\right) \quad (1)$$

where δ is the skin depth, that is the distance during which the field declines to 0.368% of its value just inside the barrier [6].

It is frequently required to utilise the more general equation for the skin depth at angular frequency ω, for biological materials the ratio $p = \frac{\sigma}{s\omega}$, is of the order of one $(0.1 < p < 10)$ throughout the wide frequency range, is as follows

$$\delta = \frac{1}{\omega\sqrt{\{\frac{\mu\varepsilon}{2}[(1+p^2)^{\frac{1}{2}} - 1]\}}} \quad (2)$$

μ is permeability of body material and ε its permittivity.

The power of a vertically short dipole antenna of length l and having sinusoidal current distribution I_{rms} is given by [12]

$$P = 80\pi^2(l_e/\lambda)^2 I^2{}_{rms} \quad (3)$$

where l_e is the effective length of vertically short dipole antenna and given as

$$l_e = \frac{2l}{\pi} \quad (4)$$

The field strength at a point at distance r within the range of direct ray of short dipole antenna is

$$E_{rms} = \frac{60\pi I_{rms} l_e}{\lambda r} \quad (5)$$

But for the case of grounded vertical antenna of effective length l_e, the apparent length will be $2l_e$ due to image effect, so

$$P = 320\pi^2(l_e/\lambda)^2 I^2{}_{rms} \quad (6)$$

And

$$E_{rms} = \frac{120\pi I_{rms} l_e}{\lambda r} \quad (7)$$

Eqn. (6) gives the power radiated through a sphere at the centre of which the antenna of length $2l_e$ is put. Since earth antenna radiate through a hemisphere, power radiated by it is half of that given in eqn. (6)

$$P = 160\pi^2(l_e/\lambda)^2 I^2{}_{rms} \quad (8)$$

Now taking the ratio of square of eqn. (7) to (8), we get

$$E_{rms} = \frac{\sqrt{90P}}{r} \quad (9)$$

Thus, the magnitude of electric field E_{rms} at a distance r from radiating antenna at power P

$$E_{rms} = 9.487\frac{\sqrt{P}}{r} \quad (10)$$

The heat effect resulting from the absorption of energy at frequencies greater than 100 kHz, is the key factor in how electromagnetic waves affect the human body [18]. SAR is often regarded as the most suitable metric for calculating electromagnetic exposure. Any point's SAR (W/kg) can be calculated using the induced electric field E_i (V/m) at that location [1], [8] and [14] by using the formula:

$$SAR = \frac{\sigma E_i^2}{\rho} \quad (11)$$

where, σ & ρ are the conductivity of the tissues and their mass density being used in above calculation.

Equation [15] states that when a human body of specific heat C, which is ordinarily in thermal equilibrium with its surroundings, is exposed to electromagnetic waves for a time of Δt seconds, the absorption of these waves results in a temperature change of ΔT.

$$C\Delta T = SAR(\Delta t) \quad (12)$$

3. Calculation

The tissues are penetrated by the high frequency electromagnetic waves. Thus, using equations (1) and (10), the induced electric field caused by this penetration at a depth of 1 mm in tissues is quantitatively analyzed in Table 1.

Table1. *Induced Electric Field in Different Tissues at Different Frequencies Due to Earthed Dipole Antenna of* 20 *kW at the Depth of* 1 *mm*

Tissue Name	Induced field E_i (V/m)				
	168.25 MHz	**175.25 MHz**	**182.25 MHz**	**189.25 MHz**	**196.25 MHz**
Blood	13.1167	13.1126	13.1086	13.1048	13.1011
Bone Marrow	13.3922	13.3919	13.3917	13.3915	13.3913
Brain Grey Matter	13.2449	13.2421	13.2394	13.2368	13.2343
Brain White Matter	13.2946	13.2926	13.2907	13.2889	13.2871
Cartilage	13.2560	13.2539	13.2518	13.2499	13.2480
Cerebro Spinal Fluid	12.9928	12.9860	12.9794	12.9731	12.9670
Cornea	13.1466	13.1426	13.1387	13.1350	13.1314
Dura	13.1947	13.1916	13.1887	13.1858	13.1831
Fat	13.3796	13.3793	13.3791	13.3788	13.3786
Gland	13.1975	13.1951	13.1927	13.1905	13.1884
Lens	13.2279	13.2258	13.2238	13.2218	13.2200
Mucous Membrane	13.2471	13.2445	13.2420	13.2397	13.2373
Muscle	13.2119	13.2096	13.2073	13.2051	13.2031
Skin Dry	13.2510	13.2478	13.2447	13.2416	13.2387
Vitreous Humor	13.0767	13.0725	13.0685	13.0647	13.0610

The internal fields created by RF energy absorption translate into electric current in the conducting tissues, with heat deposition as the energy's final outcome. Regardless of of field or wave nature, deposition is extremely non-uniform due to variations in penetration, conduction, and current flow. The pattern of exposed thermo-receptors and the feedback to the hypothalamus, which is utilised to construct a sense of the overall body temperature, are inexorably impacted by the distribution of heat deposition [7].

The computation of SAR values for different kinds of tissues of the human body at 100 m from transmitter by using eqn. (11) is given in Table 2. Gabriel et al. [5], [19] and [20] research is used to determine the conductivity of the body tissues.

Table 2. *Specific Absorption Rate (SAR) in Different Tissues at Different Frequencies Due to Earthed Dipole Antenna of* 20 *kW at the Depth of* 1mm

Tissue Name	Specific Absorption Rate SAR (W/kg)				
	168.25 MHz	**175.25 MHz**	**182.25 MHz**	**189.25 MHz**	**196.25 MHz**
Blood	0.2061	0.2064	0.2068	0.2071	0.2074
Bone Marrow	0.0043	0.0043	0.0043	0.0043	0.0044
Brain Grey Matter	0.1044	0.1052	0.1060	0.1067	0.1074
Brain White Matter	0.0618	0.0623	0.0628	0.0633	0.0638
Cartilage	0.0810	0.0814	0.0818	0.0822	0.0826
Cerebro Spinal Fluid	0.3642	0.3645	0.3648	0.3650	0.3653
Cornea	0.1743	0.1748	0.1754	0.1759	0.1764
Dura	0.1188	0.1191	0.1194	0.1196	0.1199
Fat	0.0073	0.0074	0.0074	0.0074	0.0074
Gland	0.1354	0.1357	0.1360	0.1363	0.1365
Lens	0.1029	0.1032	0.1034	0.1036	0.1039
Mucous Membrane	0.0960	0.0967	0.0973	0.0978	0.0984
Muscle	0.1223	0.1226	0.1229	0.1232	0.1235
Skin Dry	0.0872	0.0880	0.0888	0.0896	0.0903
Vitreous Humor	0.2555	0.2554	0.2553	0.2552	0.2552

For the calculation of rate of temperature change with time with the help of eqn. (12), mass density and heat capacity values are taken from Hirata et al. [1].

Table 3. *Temperature Change Rate in Different Tissues at Different Frequencies Due to Earthed Dipole Antenna of* 20 *kW at the Depth of* 1*mm*

Tissue Name	Rate of temperature change $\triangle T$ $(10^{-4}degC/s)$				
	168.25MHz	175.25 MHz	182.25 MHz	189.25 MHz	196.25 MHz
Blood	0.5284	0.5293	0.5302	0.5311	0.5319
Bone Marrow	0.0142	0.0143	0.0144	0.0145	0.0145
Brain Grey Matter	0.2749	0.2769	0.2788	0.2807	0.2826
Brain White Matter	0.1766	0.1781	0.1796	0.1810	0.1824
Cartilage	0.2249	0.2260	0.2272	0.2283	0.2294
Cerebro Spinal Fluid	0.9105	0.9113	0.9120	0.9126	0.9131
Cornea	0.4841	0.4856	0.4871	0.4886	0.4900
Dura	0.3299	0.3307	0.3315	0.3323	0.3331
Fat	0.0245	0.0245	0.0246	0.0247	0.0248
Gland	0.3869	0.3877	0.3885	0.3893	0.3901
Lens	0.3430	0.3439	0.3447	0.3455	0.3462
Mucous Membrane	0.2668	0.2685	0.2702	0.2718	0.2734
Muscle	0.3217	0.3226	0.3234	0.3243	0.3251
Skin Dry	0.2422	0.2445	0.2467	0.2488	0.2509
Vitreous Humor	0.6387	0.6385	0.6383	0.6381	0.6379

4. Result and Discussion

Table 1 depicts the induced electric field, while Table 2 depicts the SAR at various frequencies within the various body tissues. Table 3 shows the rate of temperature change at 100 m distance from the TV tower. These tables also represent that the rate of temperature increases in different tissues to the order of $10^{-4}\,^{0}C/s$ in the body which was previously in stable condition, considering all types of thermoregulation. The results show that rate of change of temperature increases with frequency and depends on the type of tissues. The change in temperature is maximum for cerebro-spinal fluid, vitreous humor, blood and cornea. This is due to the fact that the exposed subjects were found to thermoregulate most effectively due to increased body heat loss, mainly through sweating, as determined by the bio-heat equation. But since they have few blood veins, the tissues of our eyes are extremely susceptible to radiation damage. Because of this, they are less able than other organs to circulate blood and remove heat from radiation. In general, exposure to multiple frequencies that cause induced heating causes an increase in body temperature that causes a number of changes in the cardiovascular system, along with an increase in blood flow to the skin, skin thermal conductivity, and cardiac output, primarily since an increase in heart rate is required to maintain normal arterial pressure.

When core temperature rises by at least 1.0 C, deficiencies in learnt behaviours, particularly the disruption of ongoing operant actions, ensue. In addition, when exposed at levels high enough to noticeably raise body temperature, high frequency radiation can increase embryo and foetal losses, increase the frequency of foetal deformities and anomalies, diminish foetal weight at term, and damage male fertility. A well-known thermal impact of exposure in anaesthetized rabbits is high frequency-induced cataract [16].

5. Conclusion

Heat damage to tissues to the point of irreversible damage has been researched in animal tests and to a lesser extent on people. The above analysis shows that the microwave antenna can increase the temperature of tissues with the passes of time. Therefore these antennas must not be installed in a populated area because of radiation levels near the high power microwave transmitters and people should keep at least a distance of 100 m from the transmitters otherwise it would be harmful for human being. Therefore, people should be made aware of possible microwave hazards. Users of high power microwave generators are also advised to get their installation surveyed for microwave radiation levels. According to the study, simple comments regarding how to manage the risk from a novel and mostly unexplored microwave technology must be offered; these statements earn higher evaluations on trustworthiness and utility than more detailed technical information.

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