

Estimation, Analysis and Understanding of the Effects of Microwave Radiation on Human Brain from GSM-900 Cellular Mobile Handset

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Abstract: Human head-tissues like scalp, skull and brain parenchyma (the combination of cerebellum, grey matter and white matter) act as lossy dielectric materials at microwave frequencies. Consequently, when a person is exposed to high-power microwave radiation over a certain duration, the dielectric heating will take place within all these head-tissues resulting in an increase in head temperature. If a person is exposed to high power radiation (due to the proximity of a cell phone's transmitter while talking) over a long duration, the temperature of head-tissues (scalp, skull or brain) at a certain instant may increase beyond its nominal temperature of 37 degrees C or even may cross the maximum tolerable temperature limit of 43 degrees C of human body. This may cause disastrous conditions resulting in heat-stroke or brain-death. In this paper, a three-layer concentric dielectric sphere model of human head has been presented in detail. Using this analytical model, the effects of microwave radiation on human brain from GSM-900 cell phone's transmitters of different power classes and over different exposure durations at 900MHz in a GSM-900 Cellular Mobile Network has been estimated and analysed in terms of Specific Absorption Ratio (SAR) of different head-tissues, minimum safe distance of talking and the critical talking duration of brain-death for human.

Keywords: Base Transceiver Station (BTS), Cellular mobile handset, Critical talking duration, Dielectric loss, GSM- 900, Head-tissues, Loss tangent, Specific Absorption Ratio (SAR).

I. INTRODUCTION

Like other mobile handsets, the GSM-900 cellular mobile handset (usually called cell phone) is having both the transmit and receive sections. The cell phone uses the frequency band of 935 MHz - 960 MHz for the receive link (from BTS *i.e.*, the Base Transceiver Station to cell phone) and the frequency band of 890 MHz - 915 MHz for the transmit link (from cell phone to BTS). Consequently, when a person is talking on his/her cell phone by holding it very close to the ear, he/she will be exposed directly to the microwave radiation from the cell phone's transmitter. Since, the brain is more sensitive part of human anatomy, it will be severely affected by microwave radiation. Depending on the cell phone's power, the effects of radiation on the human brain may vary from mild to severe doses.

Literature survey was carried out to understand the scientific work carried out in the field which has reported only qualitatively the results of the effect of microwave radiation with respect to International Commission on Non-Ionizing Radiation Protection (ICNIRP), European Union (EU) and Federal Communications Commission (FCC) recommendations [1-4]. In this paper, an attempt has been made to quantify the adverse effects of microwave radiation on human brain from a BTS transmitter of cellular mobile network using a *three-layer concentric dielectric spherical model* of human head, the model whose two spherical layers and a central sphere at the core simulate the three major head-tissues namely, the scalp, the skull and the brain parenchyma (a combination of cerebellum, white matter and grey



matter). Due to the exposure of radiation over a certain duration, each layer of the dielectric (corresponding to each head-tissues) will be heated up due to its dielectric loss leading to an increase in temperature from its nominal value. Depending on the mass, specific heat, thermal conductivity, thickness and dielectric properties of the individual head-tissue, the temperature rise will be different for different head-tissues. Using this dielectric model, the instantaneous temperature values of all these head-tissues have been computed individually. From these plots, the critical parameters like *Specific Absorption Ratio* (SAR) of head-tissues, *minimum safe distance of talking* and the *critical talking duration of brain-death/heat stroke* for human for GSM-900 cell phone transmitters of different power classes (ranging from 0.8 W to 20 W) have been estimated.

Abbreviations:

BTS	Base Transceiver Station
EU	European Union
FCC	Federal Communications Commission
GHz	Giga Hertz
GSM	Global System for Mobile Communication
ICNIRP	International Commission on Non-Ionizing Radiation Protection
MHz	Mega Hertz
RF	Radio Frequency
SAR	Specific Absorption Ratio
TEM	Transverse Electromagnetic

II. MODELING OF HUMAN HEAD: A THREE-LAYER CONCENTRIC DIELECTRIC SPHERE MODEL

The *three-layer concentric dielectric sphere model* of the human head is represented by two numbers of concentric lossy dielectric spherical layers with a lossy dielectric solid sphere at the core. These two spherical layers, when one moves from outer to inner direction, represent the major head tissues namely, **scalp**, **skull** and the central sphere at the core represents the **brain parenchyma** (*i.e.*, the cerebellum, grey matter and white matter) respectively. Such a model is shown in Figure 1(a).

When the microwave radiation (at 900 MHz) from the cell-phone is incident on human head, a certain fraction of the incident power will be reflected from the air-scalp interface (the first interface) and the rest of the power will get transmitted through the scalp, skull and then finally will get absorbed in the brain (the solid central sphere as shown in Figure 1(a)). Certain amount of the transmitted power through scalp will get absorbed within the scalp-layer and the rest of the power will be incident at the scalp-skull interface (the second interface). In the similar way, some part of this power will get reflected from scalp-skull interface and the remaining will be transmitted through the skull. While transmitting through the skull, some amount of power will get absorbed within the skull and the remaining part will be incident at the skull-brain interface (the third interface). After reflection from this third interface, the rest of the power will be transmitted through the brain and will get completely absorbed in the brain. Thus, the power absorbed within the brain (the cerebellum, grey matter and white matter together) can be assumed as the incident power minus the sum of the power absorbed within scalp and skull-layers minus the sum of the reflected power from all the three interfaces that exist within the three-layer concentric dielectric sphere model of human head. Figure 1(b) represents the linear equivalent of the *three-layer concentric dielectric sphere model* of human head showing schematically the incident, reflected, transmitted and dissipated power across the different layers of human-brain when microwave power from a cell-phone is incident on the head



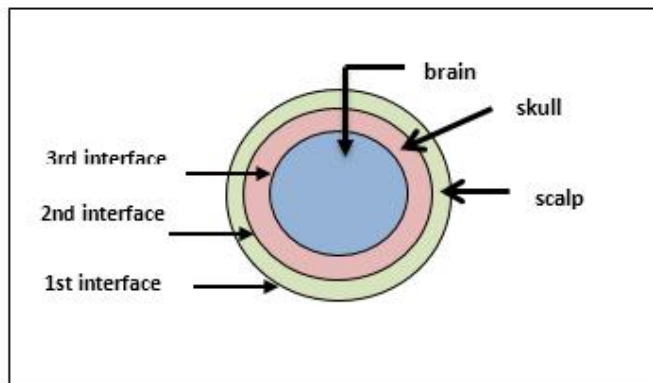


Fig. 1(a): Three-layer concentric dielectric sphere model of human head

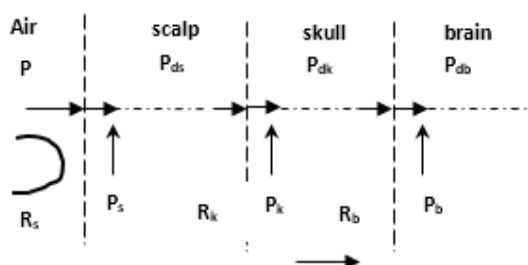


Fig. 1(b): Linear equivalent of the three-layer concentric dielectric sphere model of human head

The microwave radiation upon incident on human head will be successively dissipated within scalp and skull. The remaining power will then be completely attenuated within the brain (i.e., the cerebellum, grey matter and white matter). These power dissipations will generate the dielectric heating within each head-tissues resulting an increase in temperature of the human head. If the incident radiation level is quite large, the head temperature may exceed its nominal or permissible upper limit resulting some adverse effects on human brain.

At Radio Frequency (RF), the dielectric constant of each cylindrical layer and also of the central solid cylinder (shown by dotted line) is the complex quantity and will be represented in the following form [5-8]:

$$k^* = \epsilon_r - j\epsilon_r (\tan \delta) \quad (2.1)$$

where, the real part, ϵ_r is intended for computation of capacitance of the dielectric and the imaginary part, $\epsilon_r (\tan \delta)$ is intended for computation of power loss (also called dielectric loss) within the dielectric. The quantity, $\tan \delta$ is commonly known as loss tangent or dissipation factor.

In order to quantify the effects of microwave radiation on human head at GSM frequency of 900 MHz using this dielectric sphere model, for the sake of simplicity, the following assumptions have been considered:

The distance between the head and the cell phone (while talking) is greater than or equal 4 cm, the minimum far-field distance of the cell phone-antenna.

When a person talks on a cell phone, the 50 % of human head' surface is uniformly exposed to the microwave radiation from the cell phone's transmitter

The incident microwave power on each dielectric layer representing human head-tissues (namely, scalp, skull and brain) is always normal to the surface of the dielectric layer.

The different head-tissues (namely, scalp, skull and brain) act like unbounded dielectric media so that the microwave propagation through these tissues is always in Transverse Electromagnetic (TEM) mode.

After passing through scalp and skull-layers, the total power that is incident on the brain (represented by the solid dielectric sphere at the core in Figure 1(a)) gets completely absorbed and hence dissipated completely within the brain.



The nominal temperatures of all the head-tissues is equal to the nominal temperature of the human body (which is equal to 37 degrees C).

The dielectric constant and the dissipation factor (or loss tangent) values of the major human head-tissues at 900 MHz are shown in Table 1[9, 10].

Table 1: Dielectric Constant and the Dissipation Factor values of the major human head-tissues at 900 MHz

Human body tissues	Dielectric constants, k	Electrical conductivity (Siemen/Meter)	Dissipation factor or Loss tangent
Scalp	41.4	0.867	0.426
Skull	12.5	0.143	0.238
Brain	52.7	1.26	0.489

The thickness, surface area, mass and specific heat values of the major human head-tissues of an adult male (of weight 70 kg and of height 1.77 m) are shown in Table 2 [11-13].

Table 2: Thickness, surface area, mass and specific heat values of the major human head-tissues of an adult male

Human body tissues	Thickness (meter)	Surface area (Square meter)	Mass (Kg)	Specific heat (J/Kg/degree C)
Scalp	5.8×10^{-3}	0.0694	0.2	3391
Skull	6.5×10^{-3}	0.0586	2.5	1313
Brain	$0.167 \times 0.140 \times 0.093$ (length x width x height)	0.0480	1.4	3630

Note: The brain could be considered as a solid dielectric sphere with average radius of 0.0618 m

III. ESTIMATION OF THE EFFECTS OF RADIATION ON HUMAN BRAIN

To compute the amount of dielectric heating within different layers of human head-tissues, let us define the following parameters:

- k_o = dielectric constant of the air
- k_s = dielectric constant of the scalp
- k_k = dielectric constant of the skull
- k_b = dielectric constant of the brain
- D_s = dissipation factor (or $\tan \delta$) of the scalp
- D_k = dissipation factor (or $\tan \delta$) of the skull
- D_b = dissipation factor (or $\tan \delta$) of the brain
- L_s = thickness (in m) of the scalp-layer
- L_k = thickness (in m) of the skull-layer
- A_s = surface area (in square meter) of the scalp
- R_s = return loss (as a ratio) at the air-scalp interface
- R_k = return loss (as a ratio) at the scalp-skull interface
- R_b = return loss (as a ratio) at the skull-brain interface
- P_s = transmitted power at the air-scalp interface
- P_k = transmitted power at the scalp-skull interface
- P_b = transmitted power at the skull-brain interface
- P_{ds} = power dissipation (in watt) within scalp



P_{dk}	=	power dissipation (in watt) within skull
P_{db}	=	power dissipation (in watt) within brain
m_s	=	mass (in Kg) of the scalp
m_k	=	mass (in Kg) of the skull
m_b	=	mass (in Kg) of the brain
s_s	=	specific heat (J/Kg/degree C) of the scalp
s_k	=	specific heat (J/Kg/degree C) of the skull
s_b	=	specific heat (J/Kg/degree C) of the brain

3.1 RF Power Dissipation within Human Head-Tissues

To microwave radiation, each layer of body-tissues behaves like a lossy dielectric layer. For the incident RF power, P (in watt) at frequency, f_G (in GHz), the power dissipation, P_d (in watt) within a lossy dielectric layer of thickness L (in m), having dielectric constant, k , dissipation factor or loss tangent, D is given by the following equation [8,14]:

$$P_d \approx 21f_G P(1 - R)\sqrt{k}(D)L \quad (3.1)$$

Here, R is the return loss (as a ratio) at the air-dielectric interface and the quantity, $P(1 - R)$ represents the transmitted power through the air-dielectric interface.

The return losses, R_s , R_k , R_b (as ratio, not in dB) at the air-scalp, scalp-skull and skull-brain interfaces could be expressed by the following equations:

$$R_s = \left[\frac{(\sqrt{k_0}) - (\sqrt{k_s})}{(\sqrt{k_0}) + (\sqrt{k_s})} \right]^2 \quad (3.2)$$

$$R_k = \left[\frac{(\sqrt{k_s}) - (\sqrt{k_k})}{(\sqrt{k_s}) + (\sqrt{k_k})} \right]^2 \quad (3.3)$$

$$R_b = \left[\frac{(\sqrt{k_k}) - (\sqrt{k_b})}{(\sqrt{k_k}) + (\sqrt{k_b})} \right]^2 \quad (3.4)$$

Using the values of dielectric constants of head-tissues (as shown in Table 1) in Equations (2.2) to (2.4), the return losses, R_s , R_k , R_b are computed as follows:

$$R_s = 0.53, R_k = 0.08, R_b = 0.12$$

I. Scalp-tissue:

When a person is talking on cell phone, his/her scalp will be directly exposed to RF radiation and 50 percent of the surface area of his/her scalp will have the maximum incident RF power level. A portion of the incident power, P will be reflected back from the air-scalp interface and remaining power that will be transmitted through this interface will be given by

$$P_s = P(1 - R_s) \quad (3.5)$$

The power, P_s when propagating through the scalp, a portion of it will be dissipated within the scalp and the remaining will be incident at the scalp-skull interface. Using Equations (3.1) and (3.5), the power dissipation within scalp could be expressed as follows:

$$P_{ds} = 21f_G P(1 - R_s)\sqrt{k_s}(D_s)L_s \quad (3.6)$$

where, $R_s = 0.53$

II. Skull-tissue:

The power incident at the scalp-skull interface will be equal to the transmitted power (P_s) minus the dissipated power (P_{ds}) within scalp. This means incident power at the scalp-skull interface is equal to ($P_s - P_{ds}$). A



portion of this power will be reflected back from the scalp-skull interface and the remaining power that will be transmitted through this interface is given by

$$P_k = (P_s - P_{ds})(1 - R_k) \quad (3.7)$$

The power, P_k when propagating through the skull, a portion of it will be dissipated within the skull and the remaining will be incident at the skull-brain interface. Using Equations (3.1) and (3.7), the power dissipation within skull could be expressed as follows:

$$P_{dk} = 21f_G(P_s - P_{ds})(1 - R_k)\sqrt{k_k}(D_k)L_k \quad (3.8)$$

Combining Equations (3.5), (3.6) and (3.8), one could write,

$$P_{dk} = 21f_G P(1 - R_s)(1 - R_k)[1 - 21f_G\sqrt{k_s}(D_s)L_s]\sqrt{k_k}(D_k)L_k \quad (3.9)$$

where, $R_s = 0.53$ and $R_k = 0.08$

III. Brain-tissue:

The power incident at the skull-brain interface will be equal to the transmitted power (P_k) minus the dissipated power (P_{dk}) within the skull. This means incident power at the skull-brain interface is equal to $(P_k - P_{dk})$. A portion of this power will be reflected back from the skull-brain interface and the remaining power that will be transmitted and completely absorbed and dissipated within the brain (under assumption-5 in section 2) will be given by

$$P_{db} = (P_k - P_{dk})(1 - R_b) \quad (3.10)$$

Combining Equations (3.7), (3.9) and (3.10), one could write,

$$P_{db} = P(1 - R_s)(1 - R_k)(1 - R_b)\{1 - 21f_G\sqrt{k_s}(D_s)L_s\} \{1 - 21f_G\sqrt{k_k}(D_k)L_k\} \quad (3.11)$$

where, $R_s = 0.53$, $R_k = 0.08$ and $R_b = 0.12$

During talking on cell phone, the distance between ear and cell phone is usually in the range of 3 cm to 15 cm. For most of the cell phones, the antenna is a quarter wave dipole antenna. For such dipole antenna, the minimum far field distance at 900 MHz (of wavelength 33.3 cm) is nearly equal to 4 cm (or 0.04 meter). Then the total power (P) incident (in W) on human scalp when talking to the cell phone by holding the handset at a distance, r (in meter) from the scalp (where, r is greater than or equal to 0.04 meter) will be given by the following equation (under the assumption-1 in section-2 i.e., under far-field condition):

$$P = \frac{P_t G_t (0.5A_s)}{4\pi r^2} \quad (3.12)$$

Where, G_t = Transmit antenna gain

For GSM-900 cellular mobile network, the transmit power of the cell phone-transmitter ranges from 0.8 watt to 20 watts and the transmit-antenna gain of cell phones ranges from 2 to 3 dB.

Putting, $A_s = 0.0694$ (see Table 2 for surface area of human scalp), $\pi = 3.14$ and assuming the antenna gain equal to 3 dB (= 2 in linear scale) in Equation (3.12), one could write,

$$P = \frac{0.0055P_t}{r^2} \quad (3.13)$$

The GSM-900 Cell Phone Power Classes are shown in Table 3 [15,16].

Table 3: GSM-900 Cell Phone Power Classes and the corresponding Transmit Output Power

GSM-900 Cell Phone Power Class	Maximum transmit-output power (W)
Class-1	20
Class-2	8



Class-3	5
Class-4	2
Class-5	0.8

3.2 Specific Absorption Ratio (SAR)

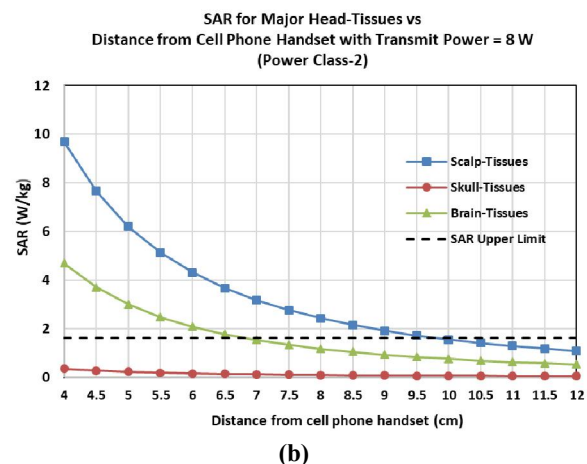
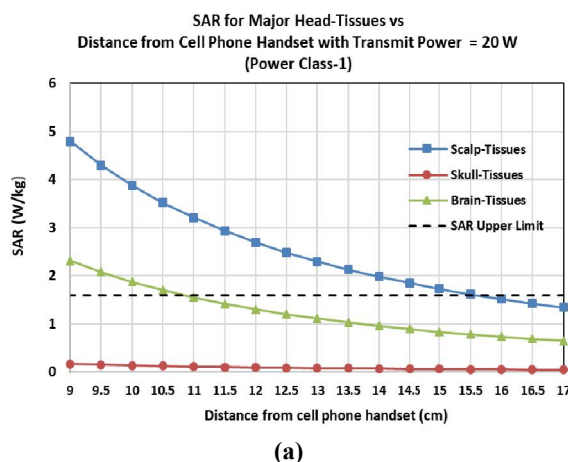
The SAR is an indicator for the health standard which is specially used for the impact of near field radiation on mobile phones and other portable communication devices on human health. SAR is defined as how much the microwave radiation power (in watt, W) from a mobile phone is being absorbed by human body-tissue of mass one kilogram (kg) and it is expressed in W/kg. The FCC limit for public exposure from cell phone is an SAR level of 1.6 W/kg. Mathematically, the SAR for a head-tissue could be expressed by the following equation,

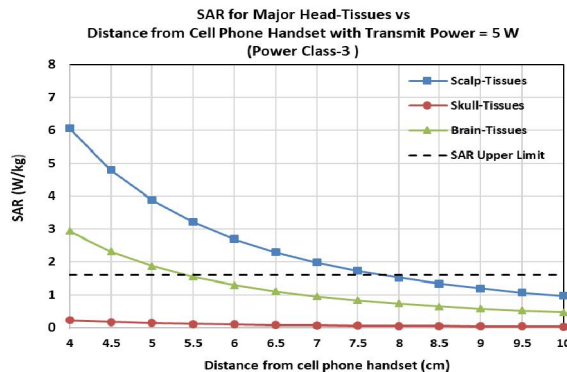
$$SAR = \frac{P_d}{m} \quad (3.14)$$

where, P_d is the dissipated power (in W) within the head-tissue of mass, m (in Kg)

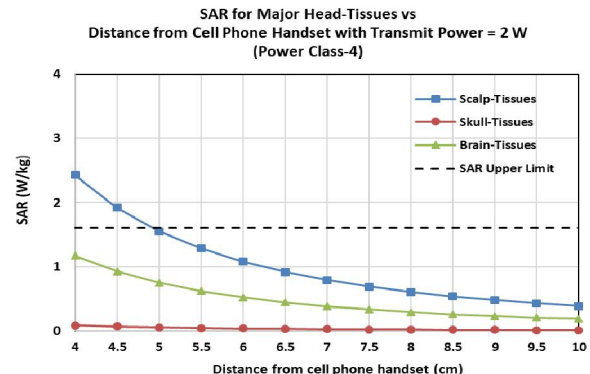
Using Equation (6.2), one could estimate the total incident power, P on human scalp at a known distance, r from a cell phone-transmitter having known transmit power, P_t . Consequently, the power dissipations within all the major head-tissues could then be estimated using Equations (3.6), (3.9) and (3.11) using the values of electrical and physical parameters of human head-tissues as shown in Tables 1 and 2. Consequently, using Equation (3.14), the SAR values could be estimated.

The SAR values for all these major head-tissues estimated in this way due to microwave radiation from cell phone-handset (with five different power classes having transmit power of 20 W, 8 W, 5 W, 2 W and 0.8 W respectively) at 900 MHz corresponding to different distances from cell phone handset within its far-field region are shown graphically in Fig. 2(a) to 2(e).

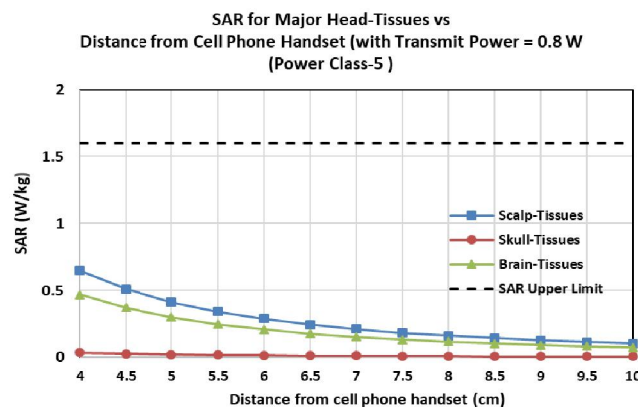




(c)



(d)



(e)

Fig. 2: Specific absorption ratios of head-tissues vs the distance from the cell phone of (a) power class-1 (b) power class-2 (c) power class-3 (d) power class-4 and (e) power class-5

The *Minimum safe distance of talking* is defined as the minimum gap between the human-head and the cell phone handset while talking above which the SAR value of any tissues (scalp, skull or brain) of human head will be below its specified upper limit *i.e.*, below 1.6 W/kg. Hence, to get rid of harmful effect of radiation from the cell phone of a particular power -class, one should hold the cell phone from the head at a distance greater than or at least equal to the *minimum safe distance of talking* for that power-class. Obviously, when the gap between the head and the cell-phone is less than the *minimum safe distance of talking*, SAR value will exceed its upper limit causing harmful effects on the human-brain.

From the plots at Figures 2(a) to 2(e), the *minimum safe distances of talking* corresponding to the GSM-900 cell phone handsets of five different power classes as estimated are shown in the Table 4.

Table 4: Maximum transmit power and minimum safe distance of talking for cell-phones of different power classes

GSM-900 Cell Phone Power Class	Maximum transmit-output power (W)	Minimum safe distance (cm) of talking
Class-1	20	15.5



Class-2	8	10
Class-3	5	8
Class-4	2	5
Class-5	0.8	< 4

3.4 Instantaneous Temperature of Human Head-Tissues due to Dielectric Heat Generation

Let us consider that a person is talking on his/her cell phone in such a place, where all the heat-transfer processes are absent. Under this worst situation, the temperature of all the head-tissues will go on increasing indefinitely with exposure time. Consequently, the instantaneous temperature (T_i) of a dielectric layer over the exposure time, T_e (in seconds) due to its dissipated power, P_d could be obtained using Joule's law of heating as follows:

$$ms(T_i - T_n) = P_d T_e \quad (3.15)$$

On simplification of Equation (3.15),

$$T_i = T_n + \frac{P_d T_e}{ms} \quad (3.16)$$

where,

- m = mass of the dielectric layer (in Kg)
- s = specific heat of the dielectric layer (in J/Kg/degree C)
- T_n = initial or nominal temperature of the dielectric layer (in degree C)

The mass and specific heat of the head-tissues are known (see Table 2). Now, let us assume that the initial temperatures of all the head-tissues are identical and equal to the nominal temperature (of 37 degrees C) of human body.

Consequently, putting $T_n = 37$ and substituting the power dissipation (P_d) corresponding to different body-tissues from Equations (3.6), (3.9) and (3.11) into the Equation (3.16), the instantaneous temperatures of the different head-tissues could be expressed as follows:

(1) Scalp-tissue:

The instantaneous temperature, T_s (in degree C) of the skin-tissue will be given by

$$T_s = 37 + \frac{[21f_G P (1-R_s) \sqrt{k_s(D_s)L_s}] T_e}{ms} \quad (3.17)$$

where, m and s are the mass and specific heat of scalp-tissue respectively

(2) Skull-tissue:

The instantaneous temperature, T_f (in degree C) of the skull-tissue will be given by

$$T_k = 37 + \frac{[21f_G P (1-R_s)(1-R_k) \{1-21f_G \sqrt{k_s(D_s)L_s}\} \sqrt{k_k(D_k)L_k}] T_e}{ms} \quad (3.18)$$

where, m and s are the mass and specific heat of skull-tissue respectively

(3) Brain-tissue:

The instantaneous temperature, T_m (in degree C) of the muscle-tissue will be given by

$$T_m = 37 + \frac{[P(1-R_s)(1-R_k)(1-R_b) \{1-21f_G \sqrt{k_s(D_s)L_s}\} \{1-21f_G \sqrt{k_k(D_k)L_k}\}] T_e}{ms} \quad (3.19)$$

where, m and s are the mass and specific heat of brain-tissue respectively

In Equations (3.17) to (3.19), the incident power, P (as given by Equation (3.13)) depends on the cell-phone's power class and the talking distance, *i.e.*, the gap between the head and the cell-phone while talking.

Using the electrical, thermal and physical parameter values (as shown in Tables 1 and 2), in Equations (3.17) to (3.19), the instantaneous temperatures of all the major head-tissues due to radiation from cell-phones of four different power classes (Class-1 to Class-4) when held at their respective minimum *safe distances of talking* (as shown in Table 3) are



computed over different talking durations (or talking time). Since, for power class-5, the minimum safe distance is less than 4 cm, which is in the near-field region of the cell-phone antenna, the instantaneous temperatures of the head-tissues for power class-5 cannot be computed using the analytical method shown in the paper (see the assumption-1 in section-2).

Consequently, the temperatures versus the talking duration for the power class-1 to power class-4 as computed in this way are shown graphically in Figures 3(a) to 3(d).

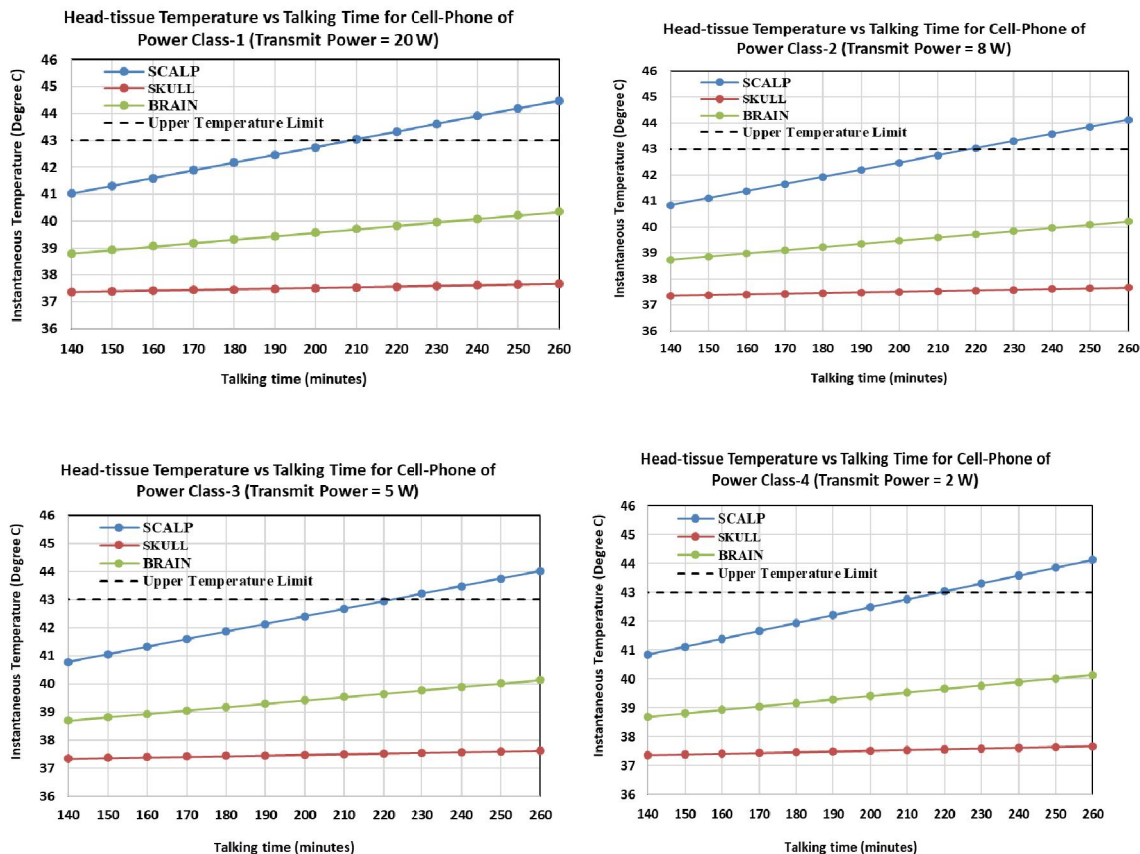


Fig. 3: Instantaneous temperatures of different head-tissues vs talking time for

(a) Cell-phone power class-1 (b) Cell-phone power class-2 (c) Cell-phone power class-3 (d) Cell-phone power class-4 when the cell-phone is held at the respective minimum safe distances of each power class

3.4 The Critical Talking Duration of Brain-death/Heat stroke

The *critical talking duration of brain-death/brain stroke* is defined as the maximum duration of talking on cell-phone above which the physical temperature of any head-tissues will exceed its upper limit of 43 deg C. From the plots in Figures 3(a) to 3(d), it is concluded that the critical talking duration (corresponding to the minimum safe distance of talking) is almost the same and is equal to about 220 minutes (which is equal to 3 hours 40 minutes) for the cell-phones with power class-2 to power class-4. For the cell-phone with power class-1, its value is little less equal to 210 minutes.

It is to be noted that the instantaneous temperatures of the head-tissues versus the talking duration for the cell-phones of different power classes as shown in the Figures 3(a) to 3(d) are computed when the gap between the head and



the cell-phone is equal to the *minimum safe distance of talking* of the phone of that power class. The *minimum safe distance of talking* and the *critical talking duration of brain-death/heat stroke* corresponding to their *minimum safe distance of talking* for the cell-phones of different power classes (power class-1 to power class-4) are shown in Table 5.

Table 5: Minimum safe distance of talking and the critical distances of brain-death/heat-stroke

Cell Phone Power Class (transmitter power in W)	Minimum safe distance (cm) of talking	Critical Talking Duration of Brain- death/Brain Stroke (minutes)
Power Class-1 (20 W)	15.5	210
Power Class-2 (8 W)	10	220
Power Class-3 (5 W)	8	220
Power Class-4 (2 W)	5	220

IV. DISCUSSIONS

From the analytical results as presented in section 3, the following points could be derived:

For a cell-phone of any power class, the SAR level is maximum for scalp and minimum for skull. For the brain, the SAR level lies in between of scalp and skull (2) As the cell-phone power class increases (i.e., the cell-phone transmit power decreases), the minimum safe distance of talking decreases. A person while talking on a cell-phone of particular power class, he/she must maintain the minimum safe distance corresponding to that power class (given in Table.4) so as to avoid the health hazard due to radiation.

(3) Due to the radiation from a cell-phone of any power class, the scalp temperature first exceeds the upper limit of body temperature (which is equal to 43-degree C) during talking. So, for any power class, the critical talking duration of brain-death/heat-stroke will be mainly determined by the scalp temperature rise during talking.

(4) The critical talking duration of brain-death/heat stroke corresponding to the minimum safe distance is almost the same (which is about 220 minutes) for the cell-phones of power class-1 to power class 4.

(5) Even when a person maintains the minimum safe distance of talking while using the cell-phone, he/she should limit the talking duration within the critical talking duration of brain-death/heat stroke so as to avoid the health hazard due to radiation.

V. CONCLUSION

The paper's goal was to estimate quantitatively the adverse effects of microwave radiation on human head from the cell-phone's transmitter in GSM-900 cellular mobile network. The three-layer concentric dielectric sphere model of human head that has been presented here could also be extended to estimate quantitatively the adverse effects of microwave radiation on human body (comprises of skin, fat, muscle, fat, blood, bone-cortical, bone-cortex etc.) from other high-power RF sources operating at high frequency bands. Therefore, the model will also be helpful for the technical staff to estimate the minimum safe distances from such sources and also the maximum safe exposure time when working on high power laboratory or in similar environments.

At present, the experimental verification of this model is quite difficult due to the risk factors involved with human life while performing the experiments. Hence, the accuracy of the three-layer concentric dielectric sphere model of human head mainly depends on the accurate values of the physical, thermal and electrical properties of different head-tissues that are available in various medical journals/literatures. The accuracy of the model also depends on the accurate values of the mismatch losses that are present at the scalp-air interface and at the interfaces between two adjacent head tissue-layers, which are quite difficult to measure experimentally at present. So, the human head model presented here is an approximate model which could be fine-tuned in near future by conducting a series of experiments on human head-tissues without any risk factors involved.



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