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Environmental Pollution of Cellular Mobile Base Station in Populated Areas

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ABSTRACT

Cellular mobile communication technology has grown exponentially in the last decade resulting in large number of base stations in areas at which people are living or working. All over the world, the electromagnetic pollution produced from cellular base stations erected in residential areas and its effect on the environment and human body is a problem that has been concerning the society for many years.

This paper, introduces the effects of electromagnetic energy emitted by cellular base stations on the biological systems of the human body. The induced electromagnetic fields (EMF), and specific absorption rate (SAR) were calculated in close proximity to cellular mobile base stations.

The calculated values of SAR were compared with the most commonly used international limits. The results show that the electromagnetic radiation (EMR) exposure levels at a distance of several meters from the base station towers can cause hazardous effects to the public.

Keywords: Electromagnetic radiation (EMR), Electromagnetic pollution, Cellular mobile communication systems, SAR, Mobile effects on human health.

التلوث البيئي لمحطات الهاتف الخليوي النقال في المناطق السكنية

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الملخص

تطورت تكنولوجيا الهاتف الخليوي النقال بشكل متزايد في العقد الأخير مما نتج عنه محطات أكثر في المناطق التي يسكن أو يعمل فيها الناس. في كل أرجاء العالم ، الإشعاعات الكهرومغناطيسية المنبعثة من محطات القاعدة الخلوية المنصوبة في المناطق السكنية وتأثيراتها على البيئة و جسم الإنسان وتمثل مشكلة مقلقة للمجتمع منذ عدة سنوات. يعرض هذا البحث تأثيرات الطاقة الكهرومغناطيسية المنبعثة من محطات القاعدة الخلوية على الأجهزة الحيوية لجسم الإنسان . تم احتساب كثافة القدرة، المجالات الكهرومغناطيسية المحتثة ومعدل الامتصاص النوعي في المناطق القريبة من محطات الهاتف النقال . تمت مقارنة معدل الامتصاص النوعي المحتسبة بالمعايير الدولية الأكثر استخداما وقد بينت النتائج بان مستوى التعرض للمجالات الكهرومغناطيسية عند بضعة أمتار من محطات القاعدة ممكن أن يسبب تأثيرات خطيرة على عامة الناس.

1. Introduction

The Global System for Mobile communications (GSM) are second-generation (2G) systems were adopted in many countries all over the world. Base station antennas transmit in the frequency range of 935 to 960 MHz (GSM-900), 1810 to 1880 MHz (GSM-1800). 3G cellular system has been adopted in many countries, in which base station antennas transmit in the frequency range of 2110-2170 MHz [1] [2].

Base station antennas are usually mounted on the roofs of buildings or on free-standing masts, and down-tilted, so that the signals are directed towards ground level.

Cellular mobile communication system operates via base stations, and each base station covers a limited region(cell) [3]. The widespread use of cellular phones requires more base stations to provide good coverage, as sitting base stations far from the user will result in poor quality link, and causes the phones to increase their output power to sustain the connection. Therefore, many base stations were erected in areas of high population density.

The presence of base station towers in residential areas is certainly discomforting and a cause of serious concern regarding the potential hazardous effects on people, particularly for those living or working in the vicinity of these base stations [2] [4].

Exposure of the general public to non-ionizing radiations from mobile base stations, TV /radio broadcasting transmitters, and other wireless networks is almost continuous. Exposure guidelines are always based on the thermal effects of the radio frequency (RF) energy which can be evaluated in terms of specific absorption rate (SAR), and RF field intensities [4].

The objective of this paper is to develop a simplified theoretical method to assess the effect of RF radiation on people living nearby GSM base station, depending on the prediction of the induced electric field around the base station transmitting antenna, calculation of the penetrated electric field and (SAR) inside the human body tissues. Finally, compliance of the calculated values of SAR has been evaluated with the guidelines given by the most known authorities.

2. Material And Methods

a. RF Field – Power Density Variation

As the human body consists of 70% liquid, the main effect of exposure to microwave is the heating of body tissues in a way that is similar to cooking in microwave ovens, leading to increase in body temperature. The effect of microwave (MW) radiations on biological systems depends on the radiation frequency, power level, dielectric constant, conductivity of the tissue, and exposure time[3] [5].

Radiation from base station in the far-field region is usually defined by the power density, or field intensities. The power density (S) and field components in air are relating by the equations [6]:

$$S = \frac{E_o^2 \epsilon_o c_o}{2} = \frac{P_t G_t}{4\pi r^2} \quad (1)$$

$$E_o = \sqrt{\frac{2}{4\pi \epsilon_o c_o}} \cdot \frac{\sqrt{P_t G_t}}{r} = 7.74 \frac{\sqrt{P_t G_t}}{r} \quad (2)$$

Where E_o is the electric field intensity in free space, P_t is the transmitted power, G_t is the transmitting antenna gain, r is the distance between the RF source and the exposed point, ϵ_o is the free space permittivity, and c_o is the radio wave speed.

The geometry illustrated in Figure 1, shown below will be used to determine the power density on each point of the exposed body that receives the RF power from the base station as a monopole antenna.

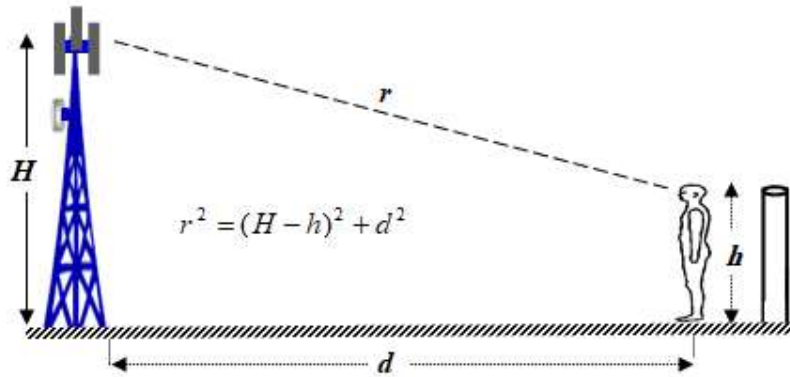


Fig. 1: Power Density and Electric Field Calculations Geometry.

b. Penetration Depth Estimation

When electromagnetic radiations are penetrated inside the human body, the incident power density will be reduced by a factor of e^{-2} . The depth at which the induced field is reduced to $1/e$ (about 0.367) compared to its magnitude at the surface of any material is

called the (skin depth). Therefore, the field (E_i) at a depth distance, z , due to the incident field E_o , on the surface is given as [5]

$$E_i = E_o e^{-z/\delta} \quad (3)$$

where δ , is the skin depth in any material that can be given by [7]:

$$\delta = \frac{1}{\omega} \sqrt{\frac{2}{\mu \varepsilon}} \left[\sqrt{1 + \left(\frac{\sigma}{\omega \varepsilon} \right)^2} - 1 \right]^{-0.5} \quad (4)$$

$$\omega = 2 \pi f, \quad \mu = \mu_o \mu_r, \quad \varepsilon = \varepsilon_o \varepsilon_r \quad (5)$$

where ω is the angular frequency, f is the frequency, σ is the conductivity, μ is the permeability, μ_o is the permeability of vacuum, μ_r is the relative permeability, ε is the permittivity, ε_o is permittivity of vacuum, and ε_r is the relative permittivity.

c. SAR Calculation

When a human body is exposed to electromagnetic radiations, it absorbs radiation and results in heating of biological tissue. The amount of heat required to change a unit mass of a substance by one unit of temperature is called the specific heat; its unit is J/(kg.K) or J/(kg.°C). The average specific heat that has been used for the human body is 3470 J/(kg.°C). Hence, the relationship between heat quantity absorbed by the human body, and temperature change is given as [8] [5]

$$\Delta Q = 3470 m(\Delta T) \quad (6)$$

where Q is the heat energy absorbed or dissipated in joule (J), m is the mass of the substance(kg), ΔT is the change in temperature(°C).

Exposure to RF energy can be determined by the Specific Absorption Rate (SAR) that is a measure of the absorbed power per mass of tissue when exposed to radiofrequency measured in watts per kilogram (W/kg). SAR is the time derivative of the incremental energy absorbed by or dissipated in an incremental mass (∂m) contained in a volume element (∂V) of a density (ρ). Therefore, SAR is given as [8] [9]

$$SAR = \frac{\partial}{\partial t} \left(\frac{\Delta Q}{\partial m} \right) = \frac{\partial}{\partial t} \left(\frac{\Delta Q}{\rho \partial V} \right) \quad (7)$$

$$SAR = \frac{1}{t} (3470 \Delta T) = \frac{3470 \Delta T}{t} \quad (8)$$

$$SAR = \frac{\sigma E_i^2}{2\rho} \quad (9)$$

where E_i is the field inside that material (induced in tissue) (V/m), and ρ is the tissue density (kg/m^3). This relation implies that the SAR value of tissue depends on the intensity of the internal electric field, and tissue properties that are presented in Table 1.

Table 1 The Human Head-Body Tissue Properties [10].

Frequency (MHz)	Head ($\mu = \mu_o, \rho = 1000 \text{ kg/m}^3$)		Body ($\mu = \mu_o, \rho = 1000 \text{ kg/m}^3$)	
	$\sigma \text{ S/m}$	$\sigma \text{ S/m}$	ϵ_r	ϵ_r
835	41.5	0.90	55.2	0.97
900	41.5	0.98	55.0	1.05
915	41.5	0.98	55.0	1.06
1000-2000	40.0	1.40	53.2	1.52

d. RF Exposure Standards

Many international authorities provide protection for the public exposed to RF and microwave radiations through setting the permitted maximum exposure (PME) levels. The most respected standard levels are those recommended by the International Commission on Non-Ionizing Radiation Protection (ICNIRP), and those developed by American National Standards Institute and the Institute of Electrical and Electronics Engineers (ANSI/IEEE) [4].

According to the ICNIRP, the admissible power density limit in W/m^2 for the public in the frequency range between (400-2000 MHz) can be calculated as $(f(\text{MHz})/200)^{0.5}$ [3][5].

The ANSI/IEEE standard C95.1-1992 RF Safety Guideline suggests that the admissible power density limit in W/m² for the public in the frequency range between (400-2000 MHz) can be calculated as $(f(MHz)/150)^2$ [8][12].

3. Results And Discussion

Most of the cellular base station radiates a power of 20 watt, through an antenna of 18dBi gain (63.095), therefore, the maximum power density (S) will be in an area near the base station antenna, and is inversely proportional to the square of the distance (r) as can be noticed from equation 1. For different heights of base station antenna (H), the power density (S) in W/m² is plotted for different exposed body heights (h) when it is located at different distances (d) from the radiating source. Figure 2, shows that the power density has no considerable variation with the height of the exposed body while it decreases as the distance (d) and transmitting antenna height (H) is increased. Therefore, increasing the base station antenna height can be used as one of the main technique for RF pollution reduction. Furthermore, the power density at a distance of 30 m from the base station doesn't exceed 0.9 W/m² which is below the permissible limits.

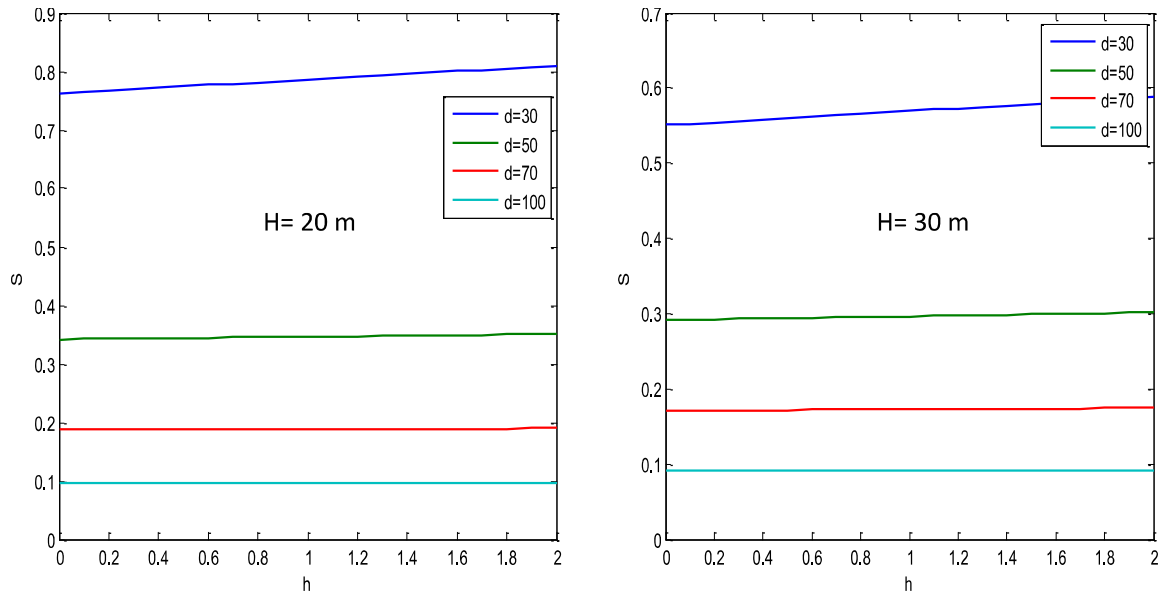


Figure 2: Power Density Variation with Exposed Body Height and Distance

The median transmits frequency of GSM-900 and GSM-1800 can be calculated to be 947.5 MHz and 1845 MHz respectively. The depth by which the electric field caused by base station radiation penetrates human body can be calculated by using equation (4) with the help of the human biological tissue characteristics given in Table 1. The penetration depth for GSM-900 was calculated to be 3.77 cm for a human body, and 3.57 cm in a human head. The penetration depth for GSM-1800 was calculated to be 2.57 cm for a human body, and 2.43 cm for a human head.

The variation of the induced field inside the human tissues is calculated by applying equation 3. Figure 3 illustrates the variation of the electric field inside the human body for different distances from GSM-900 and GSM-1800 base stations, and for different depth distances (z). It can be noticed that as depth distance increased, the field will be decreased, and the induced field in human body exposed to GSM-900 radiations is more than that

induced due to the effect of GSM-1800 base station radiation at the same depth distance when the effective radiated powers are equal.

Figure 4, shows the variation of the electric field inside the human head and body due to the radiation emitted by GSM-900 and GSM-1800 base stations respectively at 1 cm depth distance. From Figure 4, it can be seen that the induced field in the human body is more than that induced in the human head because the human body has more penetration depth due to higher conductivity and permittivity. Furthermore, the induced electric field due to GSM-900 base station radiation is more than that of GSM-1800 base station radiation, because of higher frequency results in less penetration depth.

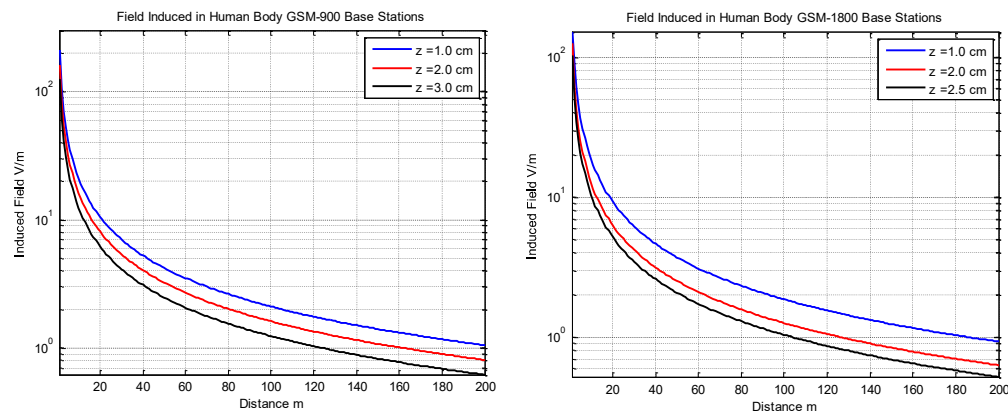


Figure 3. Induced Field inside Human Body For GSM Base Stations

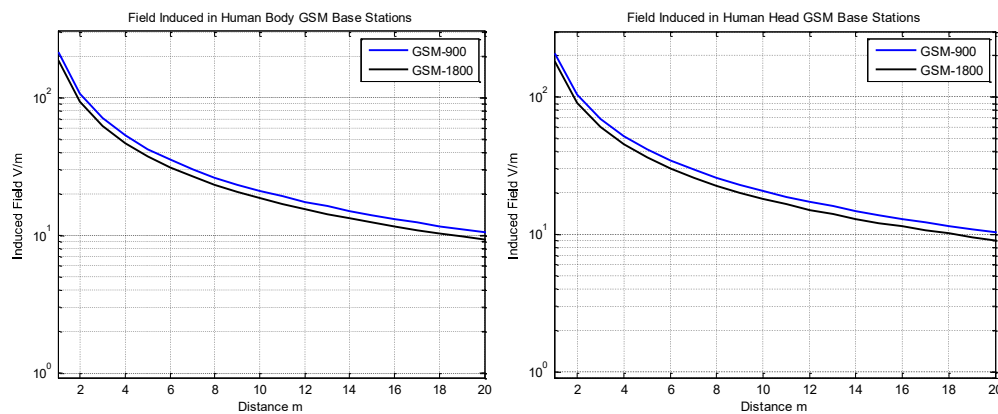


Figure 4. Field-Induced in Human Body-Head over 1 cm Penetration Distance

By using equation 9, and Table 1, the value of SAR in the human body and head were calculated for different distances from the base station tower at different depth distances. The calculated values of SAR due to GSM-900 and GSM-1800 base stations are given in Tables 2, and 3 respectively.

From these tables, it can be noticed that the amount of the absorbed RF energy decreases rapidly with increasing distance from the base station antenna. As a result, the level of exposure to radio waves at ground level is very low compared to the level close to the base station antenna. The values of SAR at a distance of 5 meters away from the GSM base station is below the safe value of SAR set by international agencies (less than 1.6 W/kg), and this implies that it is unsafe to be at a distance less than 5 meters from the base station tower for the recommended exposure time.

Table 2 The Calculated Values of SAR for GSM-900 Base Stations.

Distance from Base Station (m)	SAR in Human Body (W/kg) Depth Distance (z)			SAR in Human Head (W/kg) Depth Distance (z)		
	1.0 cm	2.0 cm	2.0 cm	1.0 cm	2.0 cm	3.0 cm
0.5	94.28	94.28	55.993	111.973	84.618	63.945
1.0	23.57	23.57	13.998	27.9934	21.154	15.986
2.0	5.89	5.89	3.4995	6.9983	5.2886	3.9965
3.0	2.61	2.61	1.555	3.1103	2.3504	1.776
4.0	1.47	1.47	0.874	1.749	1.3006	0.9991
5.0	0.94	0.94	0.5599	1.1197	0.8461	0.6394
6.0	0.65	0.65	0.3888	0.7775	0.5876	0.4440
7.0	0.485	0.485	0.285	0.5712	0.4317	0.326
8.0	0.36	0.36	0.2187	0.4373	0.3305	0.2497
9.0	0.29	0.29	0.1728	0.3455	0.2611	0.1973
10	0.23	0.23	0.1399	0.2799	0.2115	0.1598

Table 3 The Calculated Values of SAR for GSM-1800 Base Stations.

Distance from Base Station (m)	SAR in Human Body (W/kg) Depth Distance (z)		SAR in Human Head (W/kg) Depth Distance (z)	
	1.0 cm	2.0 cm	1.0 cm	2.0 cm
0.5	105.33	48.460	140.264	92.944
1.0	26.333	12.115	35.066	23.236
2.0	6.583	3.028	8.7665	5.809
3.0	2.925	1.346	3.8962	2.5817
4.0	1.645	0.7517	2.1915	1.4522
5.0	1.053	0.4846	1.4026	0.9294
6.0	0.7314	0.3365	0.9740	0.6454
7.0	0.5374	0.2472	0.7156	0.474
8.0	0.4114	0.1892	0.5478	0.3630
9.0	0.3250	0.1495	0.4329	0.2868
10	0.2633	0.1211	0.3506	0.2323

According to the ICNIRP, the admissible power density for GSM-900 base stations will be equal to (4.737 W/m²). For the case of 20 W transmitted power through an antenna of (18 dBi) gain, the safety distance can be calculated as:

$$S = \frac{f(\text{MHz})}{200} = \frac{947.5}{200} = \frac{P_t G_t}{4\pi r^2} = 4.737 \text{ W/m}^2 \Rightarrow r = \sqrt{\frac{P_t G_t}{4\pi S}} = \sqrt{\frac{20 \times 63.095}{4\pi \times 4.737}} = 4.6 \text{ m}$$

At this distance, and for 0.01m depth distance; the value of SAR can be calculated to be 1.139 W/kg which is less than the limit has set by many organizations that are 1.6 W/kg for the whole body.

With the use of the ANSI/IEEE standard, the admissible power density for GSM-900 base stations will be equal to (6.316 W/m²). For the case of 20W transmitted power through an antenna of (18 dBi) gain, the safety distance can be calculated as:

$$S = \frac{f(\text{MHz})}{150} = \frac{947.5}{150} = \frac{P_t G_t}{4\pi r^2} = 6.316 \text{ W/m}^2 \Rightarrow r = \sqrt{\frac{P_t G_t}{4\pi S}} = \sqrt{\frac{20 \times 63.095}{4\pi \times 6.316}} = 3.987 \text{ m}$$

At this distance, and for 0.01 m penetration distance; the value of SAR can be calculated to be 1.482 W/kg which is also less than 1.6 W/kg.

These results show that the calculated values of SAR agree with the power density standard limits have set by many international agencies.

4. Conclusions

The values of SAR inside the human body tissues due to exposure to non- ionizing radiation can be evaluated using a simplified theoretical approach to assess the effect of RF radiation on people living nearby GSM cellular base stations. Theoretical results show that when cellular base stations are mounted on houses rooftops, it is possible that a person at a distance less than 5.0 m or very close to the base station could be exposed to high RF levels greater than the maximum permissible exposure (MPE) limits. Hence, exposure levels exceeding the safety limits are likely to be found very close to and directly in front of the base station antennas, and at this hazardous distance, access should be limited, and should not be reached by the public.

Comparing the calculated values of SAR with ICNIRP, and ANSI/IEEE exposure limits, an idea for the compliance distance where the radiation level is safe for public exposures was estimated.

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