

Safety Distance and Power Density Calculations for GSM Communication Systems

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Abstract

The number of wireless telephone subscribers has increased at an extraordinary rate as the mobile phone has become an important part of everyday life. The rapid adoption of handheld mobile phones, leads to a growing number of mobile base stations and a growing concern for their possible adverse effects on human health.

This paper aims to assess the effects (if any) for the, low-level non-ionizing RF energy of cellular systems have on human health and to determine the safety limits needed to protect human health.

The power density and the safety distance will be calculated at different environments for Global System of Mobile Communications (GSM) cellular system, and it will be compared with the standard applied limits.

The founded that theoretical calculation of the power densities are much lower than the exposure limit that have been recommended by the international health organizations.

الخلاصة

ازداد عدد مشتركى الهاتف اللاسلكي بنسبة استثنائية لكون الهاتف الجوال أصبح جزءاً مهماً من الحياة العادية. الاستخدام السريع للهواتف الجوالية، أدى إلى ازدياد أعداد محطات القاعدة وولد ذلك قلقاً متزايداً حول التأثيرات السلبية المتعلقة بصحة الإنسان.

إن الهدف من هذا البحث هو التحقق من الآثار السلبية (إن وجدت) للموجات الراديوية واطئة القدرة للهاتف النقال على صحة الإنسان ولحساب حدود مسافة الأمان المطلوبة لحمايتها. سيتم احتساب كثافة القدرة ومسافة الأمان لبيئات مختلفة لمنظومة الهاتف النقال (GSM) وستتم المقارنة بالحدود المستخدمة عالمياً. وجد بان كثافة القدرة بالحسابات النظرية اقل بكثير من الحدود المقترحة من قبل منظمات الصحة الدولية.

I- Introduction

Electromagnetic radiation can be described as waves of electric and magnetic energy moving (radiating) together through space. Electromagnetic waves with higher frequencies like X-ray and gamma ray are called **ionizing** radiation. They have sufficient energy to cause damage to biological tissue.

Radio waves are a kind of electromagnetic fields (EMF) that consist of an electric and a magnetic component, which vary periodically in time. Radio waves belong to the part of the electromagnetic spectrum, which is called **non-ionizing** radiation. Their energy is too low to break molecular bonds and to produce heating effects causing tissue to be damaged. The intensity of the radio waves is normally expressed as power density, or as electric and magnetic field strength^[1].

In mobile communication systems, the radio wave intensity is dependent on the output power of the transmitter (mobile phone or base station antenna), and distance to that transmitter. The lower the power and the longer the distance, the lower the intensity.

The main sources of radio radiation effects are derived from transmitters and the victims become the systems receivers and individual users, who are exposed to radiations.

The increasing use of wireless systems, in particular mobile phones, and mobile laptops (PC), has generated public safety concerns relating both to the location of base station and the use of handheld receivers. Concerns have focused on human exposure to radio frequency fields and probable biological effects arising from the use of mobile phone handsets resulting from energy absorption by the head^[2,3]

When a person is exposed to the radio waves from mobile phones or base stations, most of the energy will be reflected by the body, while some of the energy will be absorbed in the tissues at the surface of the body. Due to the presence of the electromagnetic fields near the user body, certain molecules inside the body start to move because of the energy conversion into heat. The high wave intensity may cause significant heating.

The specific absorption rate (SAR), is used to specify the amount of radio frequency energy absorbed by the body per time unit when using a mobile phone. SAR is expressed in the unit watts per kilogram (W/kg)^[1,3].

II- International Safety Guidelines

In order to protect the population living around base stations and users of mobile handsets from any established health effects due to exposure to electromagnetic fields, various international guidelines and standards have been set by different organizations all over the world.

The most respected standard levels of (RF) radiation are those developed by the Institute of Electrical and Electronics Engineers and American National Standards Institute (IEEE /ANSI), and the International Commission on Non-Ionizing Radiation Protection (ICNIRP). The reference value for both standards is frequency dependent^[1,2].

Mobile telephone service providers in many countries are required to assure compliance to ICNIRP standards or to other environmental legislation. These safety guidelines are based on an analysis of the scientific research on electromagnetic fields and health and have to be applied for base station installations to avoid excessive power density from radiating antennas to exposed people^[4].

In the frequency range used for mobile communications, the Specific Absorption Rate (SAR) is difficult to be calculated in some real radio frequency exposure situations. The frequency-dependent levels are expressed in terms of power density and field strength values, and have been developed for the purpose of comparison with exposure quantities in air.

The following equations are recommended by the International Non-ionizing Radiation Committee (INIRC) to give the equivalent plane wave power density in terms of electric and magnetic fields^[3,5].

$$S = \frac{5}{6} \left[\frac{E^2}{120\pi} \right] + \frac{1}{6} [120\pi H^2] \quad (1)$$

where S is the power density, E is the electric field strength in V/m, and H is the magnetic field strength in A/m. In addition to Equation (1), the following equations can be applied to calculate the exposure limits for workers and the general public in the frequency range between (400-2000MHz) ^[5].

$$\text{Effective Electric Field Strength in (V/m)} = E = 1.375\sqrt{f} \quad (2)$$

$$\text{Effective Magnetic Field Strength in (A/m)} = H = 0.0037\sqrt{f} \quad (3)$$

$$\text{Power Density in (mW/cm}^2\text{)} = S = \frac{E^2}{120\pi} = 120\pi H^2 = 0.00051f \quad (4)$$

In equations 2,3, and 4, the frequency is expressed in MHz. The ANSI/IEEE exposure standard for the general public is 1.2 mW/Cm² for antennas operating in the 1800-2000 MHz range. The limit for antennas operating in the 900 MHz range is 0.57 mW/Cm². In the presence of multiple antennas, these standards apply to the total power produced by all antennas^[4].

III- Cellular Networks

The cellular communication systems are used to accommodate a large number of mobile units over a large area within a limited frequency spectrum. A cellular network consists of a large number of wireless subscribers who have cellular telephones (subscribers) that can be used anywhere and a number of fixed base stations, arranged to provide coverage of the subscribers ^[4]. Mobile communication networks are divided into spatial units called (cells), and each cell is served by one base station whose antennas send and receive radio signals to and from the mobile stations (phones).

Base stations are supported by, and interconnected to each other and the public switched telephone network (PSTN) via mobile switching center (MSC), as illustrated in Figure (1). The channels used for transmission from the base station to the mobiles are called forward or downlink channels, and the channels used for transmission from the mobiles to the base station are called reverse or uplink channels^[5].

When a call is placed from a cellular telephone, a signal is sent from the antenna of the phone to the nearest base station antenna which manages the call through a switching center (MSC). The farther a cellular telephone is from the base station antenna, the higher the power level required to maintain the connection. This distance determines the amount of RF energy exposure to the user.

The power of a mobile phone base station is usually described by its effective radiated power (ERP) which represents the power in the main beam that is given in watts. Alternatively, the power can be given as transmitter power (P_t) and the antenna gain (G_t). The power density (S) can be given in terms of EPR and the direct distance (r), as:

$$S = \frac{EPR}{4\pi r^2} = \frac{P_t G_t}{4 \pi r^2} \tag{5}$$

The typical power of a base station varies from several watts to 100 watts, while the radio waves emitted by cellular phone are between about 0.01 to 2.0 watts. The antenna of a hand-held cellular telephone is typically held against the side of the head when the telephone is in use. The closer the antenna is to the head, the greater a person’s expected exposure to RF energy. The amount of RF energy absorbed by a person decreases significantly with increasing distance between the antenna and the user. A cellular telephone user’s level of exposure to RF energy depends on several factors, such as the calls duration, the distance to the nearest base station, and handset specifications^[6].

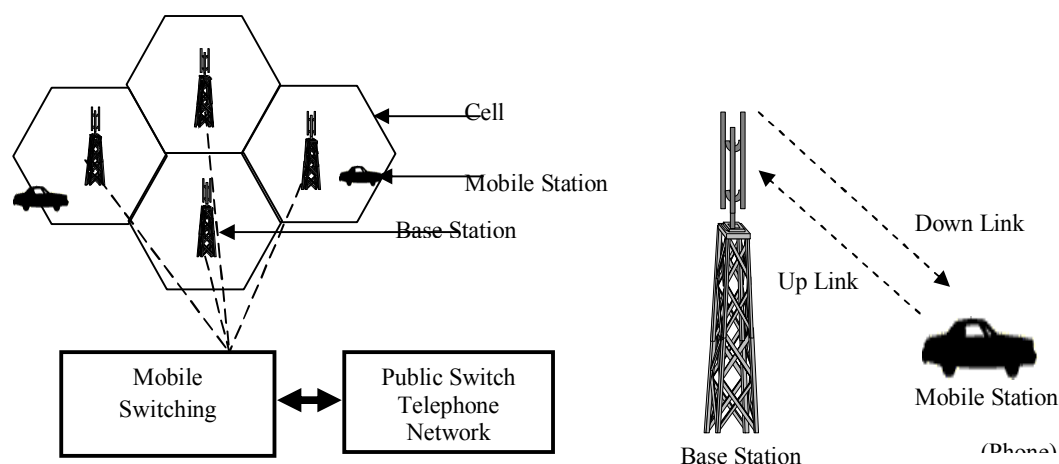


Figure-1-Basic Mobile Communication Network

Mobile communication networks operate under the Global System for Mobile Communication (GSM) is the most widely used mobile standard in many countries. GSM operates in two main frequency bands: the first is between 890 MHz and 960 MHz, that is called (GSM-900), and the second is called (GSM-1800), which operates between 1710 MHz and 1880 MHz [7].

IV- GSM Theoretical Calculations

1- Safety Distance and Power Density for GSM-900 with INIRC Limits

The GSM-900 system uses the frequency band (890-915)MHz for up-link and the band (935-969)MHz for down-link.

The medium down-link frequency (f_{med}), can be calculated as:

$$f_{med} = \frac{935 + 960}{2} = 947.5 \text{ MHz}$$

The effective electric field ,effective magnetic field, and the power density for the main beam, can be calculated according to the radiation limits given by the INIRC.

$$E_{eff} = 1.375 \sqrt{f} = 1.375 \sqrt{947.5} = 42.324 \text{ V / m}$$

$$H_{eff} = 0.0037 \sqrt{f} = 0.0037 \sqrt{947.5} = 0.1139 \text{ A / m}$$

$$S = 0.0051 f = 0.0037 * 947.5 = 0.483 \text{ mW / cm}^2$$

To find the safety distance (r) on air , we can rewrite equation (5) as;:

$$r = \sqrt{\frac{P_t G_t}{4 \pi S}}$$

Assuming a homogeneous power distribution on an antenna of a gain of 18.0 dBi gain , the safety distance can be calculated to be 4.56 m , for the transmitted power of 20 W. The relation between the base station transmitted power and the safety distance can be plotted for two different antenna gains as shown in Figure (2).

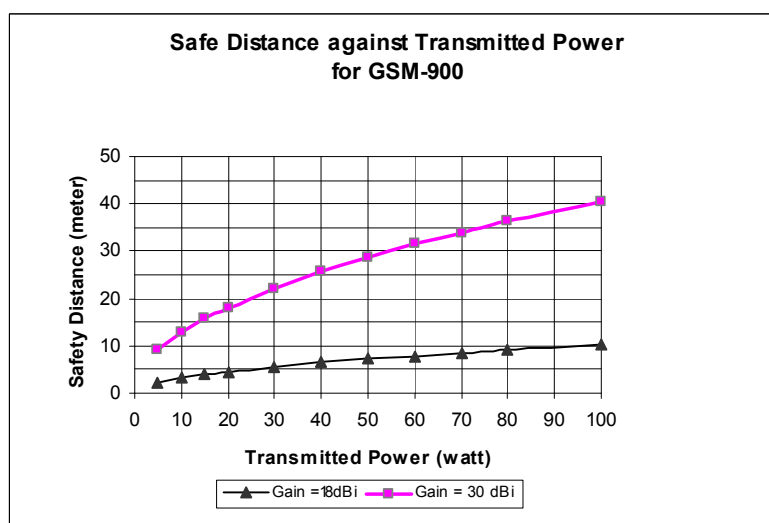


Figure.2 Safety Distance against Transmitted Power for GSM-900

From Figure (2), it can be noticed that the higher the power, the higher the safety distance. From the figure it can be also noticed that, as the antenna gain increases, the safety distance becomes higher. It is clear that for the same amount of transmitted power, the safety distance with the 18.0 dBi antenna is much lower as compared to the 30.0 dBi antenna.

2-Safety Distance and Power Density for GSM-1800 with INIRC Limits

The GSM-1800 system uses the frequency band (1710-1785)MHz for up-link and the band (1805-1880)MHz for down-link.

The medium down-link frequency (f_{med}), can be calculated as:

$$f_{med} = \frac{1805 + 1880}{2} = 1842.5 \text{ MHz}$$

For the main beam and according to the radiation limits given by the INIRC, we can find that:

$$E_{eff} = 1.375 \sqrt{f} = 1.375 \sqrt{1842.5} = 59.02 \text{ V/m}$$

$$H_{eff} = 0.0037 \sqrt{f} = 0.0037 \sqrt{1842.5} = 0.1588 \text{ A/m}$$

$$S = 0.0051 f = 0.0037 * 1842.5 = 0.939 \text{ mW/cm}^2$$

The plot of safety distance against the transmitted power with a 18.0dBi antenna, is shown in Figure (3). It can be noticed that the safety distance in GSM -900 is more than that for GSM-1800 for the same transmitted power.

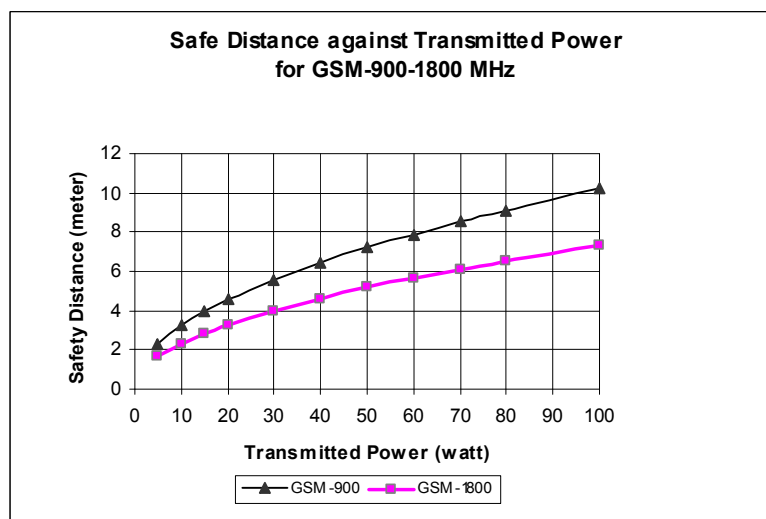


Figure.3 Safety Distance against Transmitted Power for GSM-1800

3-Safety Distance and Power Density for GSM with ANSI/IEEE Limits

The safety distance for both GSM-900 and GSM-1800 is calculated according to ANSI/IEEE limits. Figure (4) shows the safety distance against transmitted power. It has been noticed that the safety distances in GSM-1800 is about 0.69 times of the safety distance of GSM-900.

It is also found that the safety distance calculated using INIRC limits is more than that obtained by using the ANSI/IEEE limits.

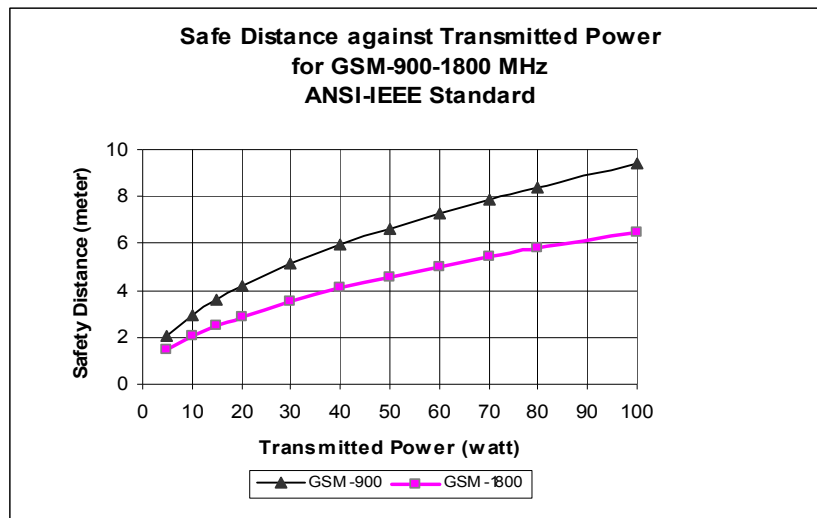


Figure.4 GSM Safety Distance against Transmitted Power with ANSI Limits

4- Safety Distance at the Ground Level (Free Space Condition)

Base station antennas that transmit the radio waves have to be installed high above the ground because radio waves travel in an approximate straight line and can be deflected by anything in their way such as trees or buildings, for that reason the base station antennas are usually mounted on towers. Those antennas emit a very small amount of energy beside, below, above or behind into empty space and the people in the vicinity of the base station cannot be in the main beam zone. Therefore, we have to take the antenna pattern into account^[6,8].

Figure (5) shows the scenario used to calculate the safety distance at the ground, that take antenna heights for both communication terminals into account. In figure (5), h_b denotes the base station antenna, h_m denotes the mobile unit antenna height, d represents the horizontal distance from the tower to the point where the calculation is done, and r is the direct distance between the transmit and receive antennas.

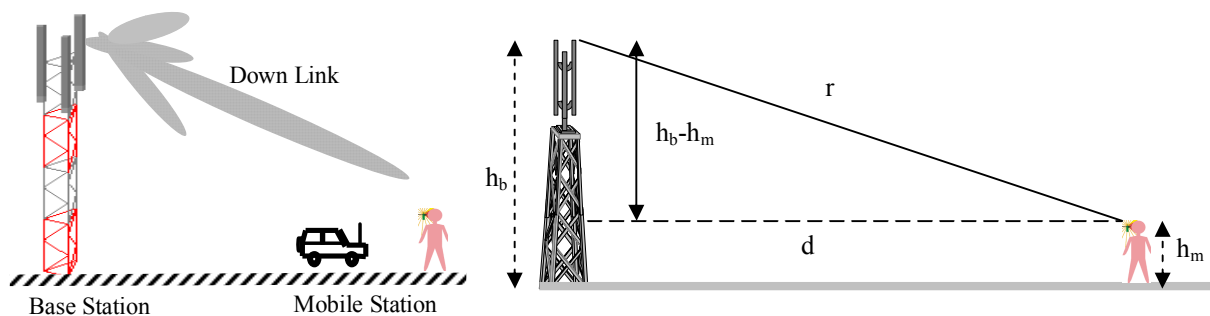


Figure.5 Ground Level Safety Distance Calculation Scenario

The power density will be given as :

$$S = \frac{P_t G_t}{4 \pi r^2} = \frac{P_t G_t}{4 \pi \left[\sqrt{(h_b - h_m)^2 + d^2} \right]^2} \tag{6}$$

$$S = \frac{P_t G_t}{4 \pi r^2} = \frac{P_t G_t}{4 \pi [(h_b - h_m)^2 + d^2]}$$

$$d^2 = \frac{P_t G_t}{4 \pi S} - (h_b - h_m)^2$$

$$d = \sqrt{\frac{P_t G_t}{4 \pi S} - (h_b - h_m)^2} = \text{Horizontal Safety Distance} \tag{7}$$

For GSM-1800 considering free-space propagation condition, and by using equation (7), the safety distance on the ground level according to the ICNIRP guidelines is calculated. It was equal to (2.817) m , for 15W transmitting power, 30 m base station antenna height, and the mobile unit antenna is of 1.5 m height, while it was calculated to be 3.948 m on air, so the safety distance at the ground level is less than on air. The safety distance against the transmitted power is plotted in Figure (6) according to ICNIRP and ANSI guidelines. From equation (7) we can show that increasing the base station antenna height leads to decrease the safety distance at the ground .

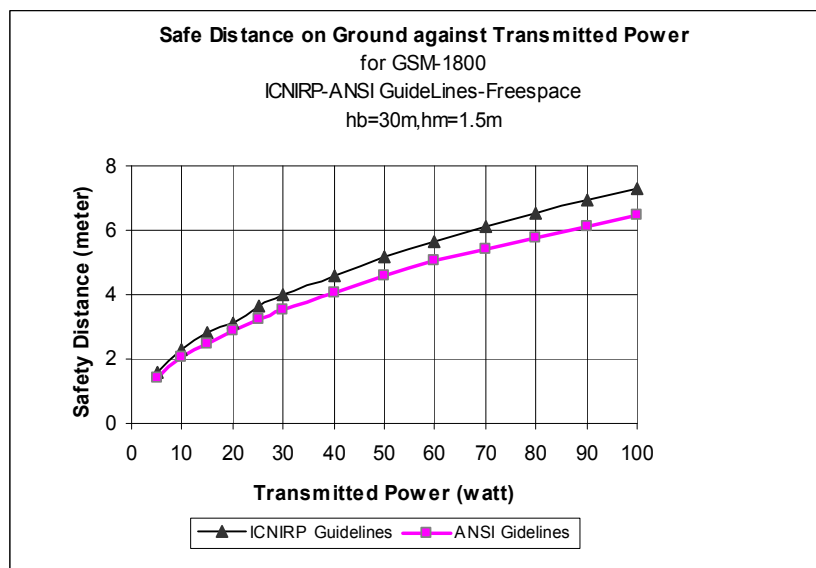


Figure.6 Safety Distance at Ground for GSM-1800

5- Power Density at The Ground in Urban Environments

In planning cell coverage area the goal is to estimate the electric field strength of the transmitted signal at the receiver end (perimeter of coverage area) [6]. The power exponent model is used to predict the power transfer between a transmitter and a receiver in different environments.

The received power (P_r) at distance (d) from the transmitting antenna can be expressed with respect to the power measured at a certain standard distance (d_o), i.e. the reference power ($P_r(d_o)$) [6,8].

$$P_r(d) = P_r(d_o) \cdot \left(\frac{d_o}{d}\right)^\gamma \quad \text{for } d > d_o \quad (8)$$

where, (γ) is the power exponent value. The value of (γ) depends on specific features of the propagation environment and it is between (2) and (5). Larger values of (γ) correspond to more obstruction and hence faster decrease in average received power as distance become larger.

This model takes into account the decrease in power density suffered by the radio wave due to spreading, as well as the energy loss due to the interaction of the wave with the propagation environment^[6]. From equation (6), we can conclude that the power density (S), is inversely proportional to r^2 ($S \propto \frac{1}{r^2}$). Generally, the power density (S), is inversely proportional to (r^γ). The value of (γ) is 2 for free space and it is equal to 4 for standard urban environment. We can write equation (6) in the following form:

$$S = \frac{P_t G_t}{4 \pi \left[\sqrt{(h_b - h_m)^2 + d^2} \right]^\gamma} \quad (9)$$

The power density for free space (S_1) at which ($\gamma = 2$), and the power density for standard urban environment ($\gamma = 4$), can be given by the following equations:

$$S_1 = \frac{P_t G_t}{4 \pi \left[\sqrt{(h_b - h_m)^2 + d^2} \right]^\gamma} = \frac{P_t G_t}{4 \pi \left[(h_b - h_m)^2 + d^2 \right]} \quad (10)$$

$$S_2 = \frac{P_t G_t}{4 \pi \left[\sqrt{(h_b - h_m)^2 + d^2} \right]^4} = \frac{P_t G_t}{4 \pi \left[(h_b - h_m)^2 + d^2 \right]^2} \quad (11)$$

$$\frac{S_1}{S_2} = \frac{P_t G_t}{4 \pi \left[(h_b - h_m)^2 + d^2 \right]} \cdot \frac{4 \pi \left[(h_b - h_m)^2 + d^2 \right]^2}{P_t G} = (h_b - h_m)^2 + d^2$$

$$S_2 = \frac{S_1}{(h_b - h_m)^2 + d^2} \quad (12)$$

From equation (12), we can decide that the power density in urban environment is less than that in free space. In addition, it can be noticed that the antenna heights is one of the main factors that control the power density. Table (1), below shows the calculated values of power density at ground in free space and in urban environment.

It can be noticed that the power density in urban area when the point of exposure is 100 m from the base station is about $0.8 \mu \text{ W/m}^2$, while it is equal to 9.3 mW/m^2 for (20W) transmitted power in both cases. The power density levels in both cases are still lower than the standard threshold power density levels.

Transmitted Power (W) = 20 W

Antenna Max. Gain (dBi) = 18 dBi

Base Station Antenna Height (m) = 30 m

Mobile Phone Antenna Height (m) = 1.5 m

Table (1) Power Density at Ground in Free Space and Urban Environment

Horizontal Distance from Base Antenna to the point of Exposure (m)	Power Density at Ground in Free-Space mW/m²	Power Density at Ground in Urban Area mW/m²
50	30	0.091
100	9.3	0.0008
150	4.3	0.00018
200	2.4	0.00006
300	1.1	0.000012

V- Conclusion

In this paper an approach to calculate power density in the vicinity of a mobile base station of GSM cellular communication system is presented.

The safety distance for GSM-900 and GSM-1800 are calculated , and all the results are compare with the limit values of the ICNIRP and the ANSI-IEEE guidelines.

It is found that the safety distance are some meters according to the ICNIRP and the ANSI-IEEE guidelines.

The factors affecting the safety distance values are presented, it was noticed that the more power emitted from network base station may increase the safety distance , so as the transmitting antenna gain. The power densities outside the main beam is presented and calculated in case of free space and in case of urban environment

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