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Electromagnetic Field Measurements near Macrocellular Base Stations

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ABSTRACT. The levels of electromagnetic radiation (EMR) to which general public is exposed and transmitted from the base stations of cellular mobile radio are investigated. The measurements of power density around base stations located in urban as well as suburban areas are obtained. The measured maximal power density at a level of 2 meters above ground is about 1.4 μW/cm^2. The variation of power density with height above ground level is shown to be linear for a relatively limited height range (1-3 meters). The measured average power density is about 1 μW/cm^2. The power level is almost steady within the suburban areas while it is rapidly fluctuating in the range of 0.2-0.6 μW/cm^2 within the urban areas, at distances greater than 40 m from the base stations. The measured level of power density is below the existing RF radiation exposure safety standards.

1. Introduction

The electromagnetic radiation from different radio frequency (RF) sources has been the subject of many investigations. These RF sources include radio and TV broadcasting stations, radar, microwave ovens and microwave communication transmitters. However, RF radiation from base stations of cellular mobile and personal communications systems (PCS) has got comparatively less attention[1]. Peterson and Testagrossa[2] measured the power densities around the base station of cellular mobile radio. The measurements were for a 96-channel system operating at an effective radiated power (ERP) of 100 watt per channel and in the frequency range 869-894 MHz. The measured maximal total power density at a level of 2 m above ground was less than 1 μW/cm^2. Near-field power density in the mean beam of a root-top mounted antenna transmitting an ERP of 1600 watt at a level of 2 m above the roof level was also measured. The power densities were found to be less than 3 μW/cm^2 at distances greater than 0.7 m from the antenna, less than 100 μW/cm^2 at distances greater than 12 m and less than 10 μW/cm^2 at distances greater than 50 m.

Cellular mobile radio of the first generation operates in the 450 or 900 MHz band. The digital second generation of the mobile phone operates, however, in the 900 MHz, 1800 MHz or 1900 MHz band. The frequency allocation for the third generation is in the 2000 MHz band. Many countries have developed RF radiation exposure standards[3-9] that show some appreciable differences as shown in Fig. 1. In the Kingdom of Saudi Arabia, good effort has been done in this direction by some local researchers[10]. As a result of differences between approaches and used frequencies, worldwide standards for the continuous exposure of the public to RF from base station antennas ranges from 0.2 to 1.2 μW/cm^2[11]. On the hand, the USSR standard for general public exposure is relatively as low as 10 μW/cm^2 in the range from 300 MHz to 300 GHz[6]. Recently, the possible health effects resulting from the exposure to low-level RF fields from communications antennas have received continuing interest and are subject to a great deal of controversy[12]. In particular, magnetic field induced reduction of melatonin and the discovery of magnetic crystals in human tissue[13] are two of the hot research points in this field.

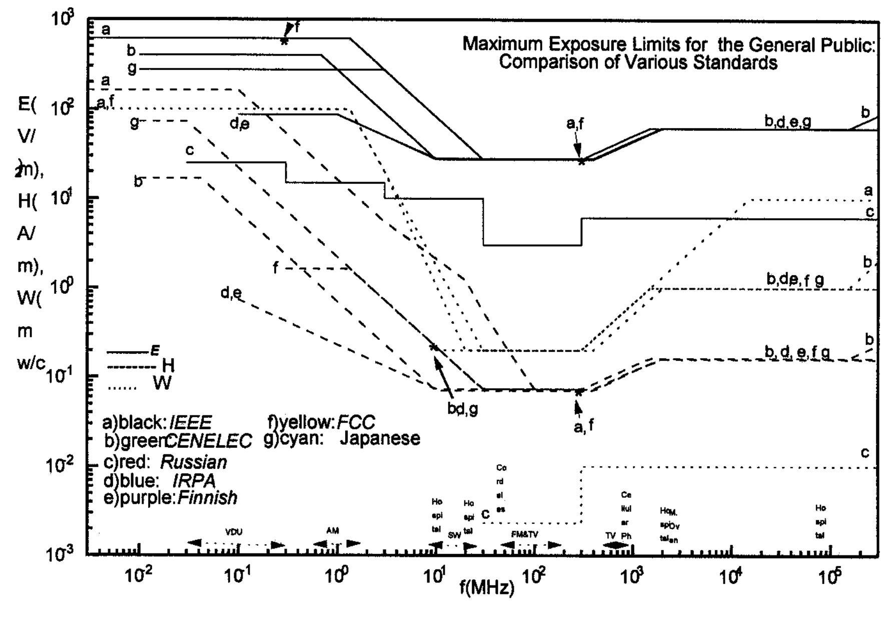

FIG. 1. Comparison of maximum exposure limits of various standards for the general public.

The tremendous growth in cellular communication services called for widespread use of cellular techniques which use base stations. Macrocell base stations which are currently used by mobile radio transmit power of about 10 watts per channel. They are usually mounted on lattice towers 25-50 m in height. Microcells with less than 1-km radius of coverage are mounted on lamp posts and surrounding buildings with average height of about 10 m and transmit between 0.1-1 watt per channel. The near future personal communications network (PCN) will use picocells which are used to provide services for areas with high terminal density and usually deployed for indoor areas with 5-30 m in height.

The possible radiation effects of these base stations must be carefully evaluated. In U.S.A., FCC[3] requires an evaluation of minimum safe distances for specific situations such as non-roof-top base station antennas less than 10 meters off the ground or root-top with a total ERP of greater than 2 kW.

This paper presents the results of measurements of electromagnetic power density in the vicinity of macrocellular radio base stations as function of distance from the base and height above ground. The base stations are chosen to be located in urban and suburban areas of a big city, which is Riyadh, Saudi Arabia to check the effects of terrain nature on the measurements. The results of measurements are compared with some of the well-known RF radiation exposure safety standards.

2. Experimental Description

The GSM network in Riyadh, Saudi Arabia divides the city into macrocells of typical radii of about 2.62 and 1.74 km for the suburban and urban areas respectively. The base station system comprises a base transceiver station (BTS) and a base station controller (BSC). Table 1 summarizes the main characteristics of some chosen base station sites in Riyadh. The transmitting antennas of the base stations are usually installed on the top of either a lattice type tower of heights 25-48 m or the roof-top of a building typically, 35-39 m in height. The antenna system is arranged in three groups (sectors a, b and c) at different angles to the azimuth. Each group consists of three linearly polarized high gain rectangular antennas which are approximately 2.3 m long and 0.3 m wide with a total down tilt of 5~10º to the vertical. One antenna in each sector is utilized for the downlink (BTS to mobile) and the other two are used for receiving signals from the mobile. The 3-dB beamwidth of the antenna radiation pattern is 60º and 7º for the horizontal and vertical directions respectively. The BTS has three to six radio terminals (RTs) with 8 time-slots per each sector of antennas. The power output of each transmitter (*i.e.* BTS to mobile) is typically 41dBm. For typical 6-dB feeder and combiner losses and typical 18 dBi antenna gain, the effective isotropic radiated power (EIRP) of BTS may reach 53-dBm.

TABLE 1. Main characteristics of chosen base stations for measurements.

Site name	Site no.	Sector	No. RTs.	EIRP (dBm)	Tower height (m)	Antennas			
						Tilt (deg.)	Az. (deg.)	Gain (dBi)	BW (deg.)
KSU #1	ZRYA 41	a b c	4 3 3	53	35	7 7 5	10 150 260	18	60
KACST	ZRYA 11	a b c	4 3 3	53	25	8 7 5	30 130 270	18	60
Olaya	ZRYA 106	a b c	4 5 6	53	48	9 10 10	40 150 270	18	60
Olaya # 2	ZRYA 23	a b c	4 4 4	53	35 35 39	10 10 10	45 135 225	18	60

For investigating the levels of electromagnetic radiation (EMR) to which the general public is exposed, the electric power density received near the towers of the four base stations is measured. Those base stations were chosen in locations such that they represent different sites in Riyadh. Table 2 summarizes the rela-

TABLE 2. Sites characteristics of chosen base stations.

Site		Characteristics				
Name and no.	Area	Building size	Building density	Building height	Vegetation index	Description
KSU #1 ZRYA 41	Suburban	Very small	Very low	1-3 stories	Low	Rural with open areas
KACST ZRYA 11	Suburban	Small	Low	2-3 stories	Low	Surburban with some open areas
Olaya ZRYA 106	Urban	Medium	High	5-8 stories	Low	Urban, dense, commercial
Olaya #2 ZRYA 23	Urban	Large	High	7-10 stories	Low	Urban, dense, commercial

tive characteristics of the sites of the chosen base stations and Fig. 2 shows a map of them, Base Station ZRYA 41 is located in a suburban area at the skirts of the King Saud University Campus (southeast of Riyadh downtown) with open flat area near the tower. Base Station ZRYA 11 is also in a suburban area and is closer to downtown but with some low-height and low-density buildings and some fairly open areas. The other two base stations are located in shopping/ commercial areas where the buildings are relatively higher and denser. Although both are located on the same road of about 50 m width, yet the base Station ZRYA 106 is characterized by more dense buildings and narrower side streets (about 10 m width) with one parking area. The transmitting antenna of base Station ZRYA 23 is installed on the rooftop of a shopping mall. The building is located at the crossing of two roads of about 50 m width each buildings of the same height at two corners and only one low height restaurant on the opposite corner.

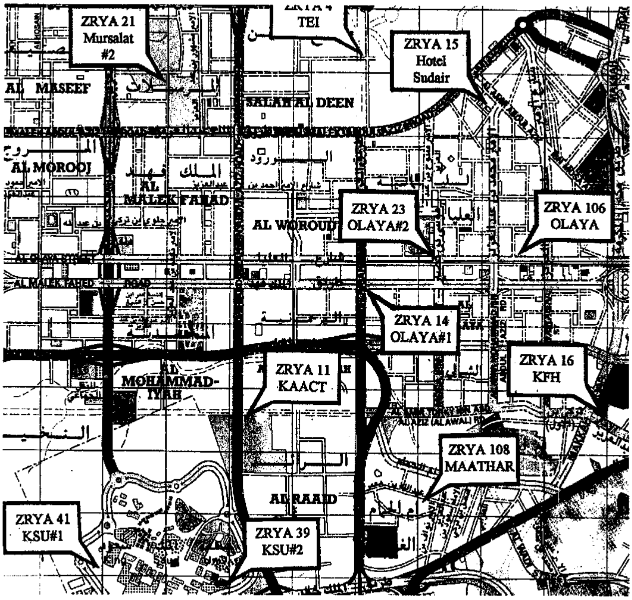

FIG. 2. Map of the chosen base stations.

The power density is measured using a radiation survey meter model Narda 8718 with an isotropic electric field probe model Narda 8760. Measurements are carried out in the frequency range of the down link (BTS-to-mobile) *i.e.* 870-960 MHz. The frequency range of measuring system is 0.3 MHz to one GHz and the full-scale measurement is 20 $\mu W/cm^2$. The minimum response time of the meter is about 0.35s and the probe has square law characteristics. Three mutually orthogonal dipole-diode sensors are supported at the end of the probe.

The meter is programmed such that it carries out 24 measurements every 30 s, then calculates their average, and updates this average and the maximum on the display. The meter-probe assembly is mounted on a wooden tripod at the normal height of 2 m. During measurements the probe is pointed directly to the source and rotated about its main axis in the vertical and horizontal planes so that maximum power is received. Measurements are carried out in steps of 20 m to about 200 m away from the base station. A calibrated wooden scale is also provided to study the variation of the electric field with heights from 2 m to 2.5 m above the ground. Calibration of the meter-probe is carried out periodically by the manufacturer.

3. Results and Discussions

Fig. 3 shows results of the measurements of the average power density S_{av} (μW/cm^2) and maximum S_{mx} (μW/cm^2) of electric field versus distance d(m) from the tower of base station #41. This figure shows that S_{mx} increases from about 0.17 μW/cm^2 at the base of the tower to about 1.1 μW/cm^2 at a distance of about 60-m from the tower and a height 2 m above the ground. Then, it starts to fluctuate until the distance d increases beyond 160 m where S_{mx} starts to decrease.

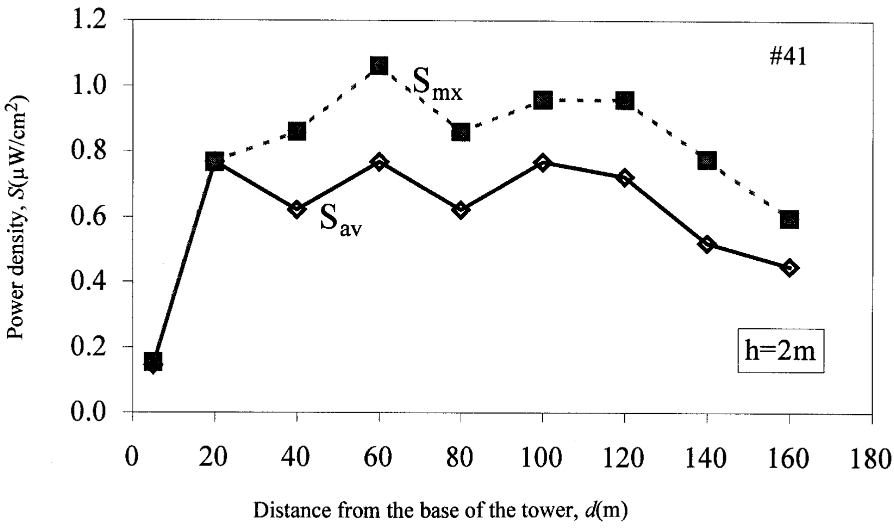

FIG. 3. Variation of maximum and average power densities, S_{mx} and S_{av}, with distance d_m from base of tower #41; height of measurements h = 2 m.

Fig. 4 shows the variation of S_{av} and S_{mx} (μW/cm^2) with height h(m) above the ground and at a distance d = 100 m from the base of the tower. The maximum power density may reach 1.4 μW/cm^2 at a height of 2.6 m above the ground; and 100 m distance from the base of the tower. As shown in Fig. 4, a linear model can represent the increase of power density (in μW/cm^2) with height increase (in meters), namely, at d = 100 m as:

$$S_{mx}\,(\mu\text{W/cm}^2) = 0.73\,h\,(\text{m}) - 0.47 \quad (1)$$

$$S_{av}\,(\mu\text{W/cm}^2) = 0.44\,h\,(\text{m}) - 0.1 \quad (2)$$

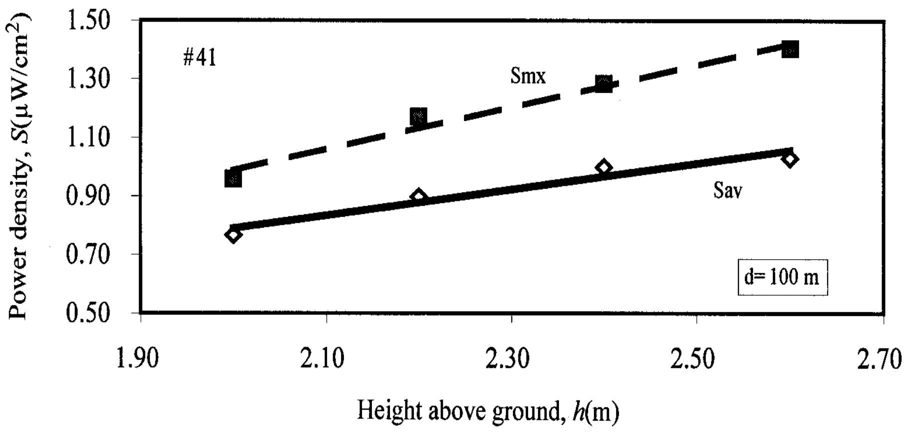

FIG. 4. Fitting the variation of maximum and average power densities, *Smx* and *Sav,* with height above the ground h (m), to a linear model at distance d = 100 from base #41.

Fig. 5 shows the results of the average power density S_{av} versus distance d from the tower of base Station ZRYA 106 in the south and east directions. It is shown that the power is direction-dependent relative to the base station antennas. However, the power density does not exceed 0.45 μW/cm^2 and is relatively less than that of base Station ZRYA 41. Fig. 6 shows the variation of the power density S_{av} (μW/cm^2) with distance d (dm) from the tower of base Station ZRYA 11.

At first, the power density increases with the increase of distance from the tower; from about 0.1 μW/cm^2 at the foot of the tower to about 1 μW/cm^2 at a distance of 40 m. Then the power density starts decreasing and fluctuating around 0.6 μW/cm^2 as the distance increases to 200 m. The fluctuation may be attributed to the effect of multipath propagation from the transmitting antenna on the tower to the receiving probe.

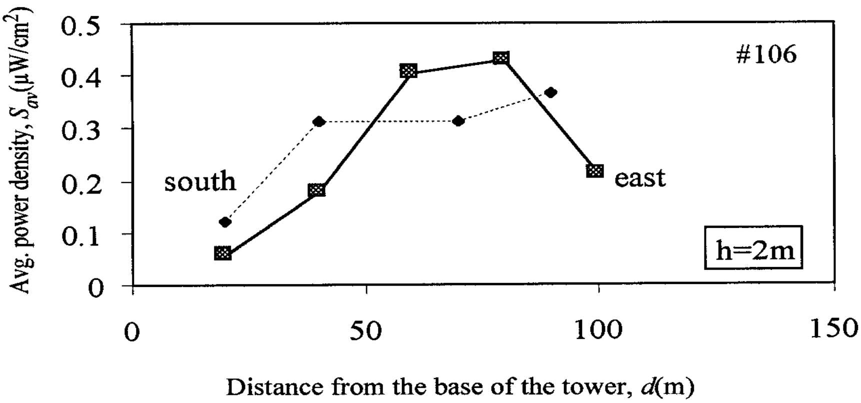

FIG. 5. Variation of the average power density S_{av} (μW/cm^2) with distance d (m) from base stations #106 in east and south directions.

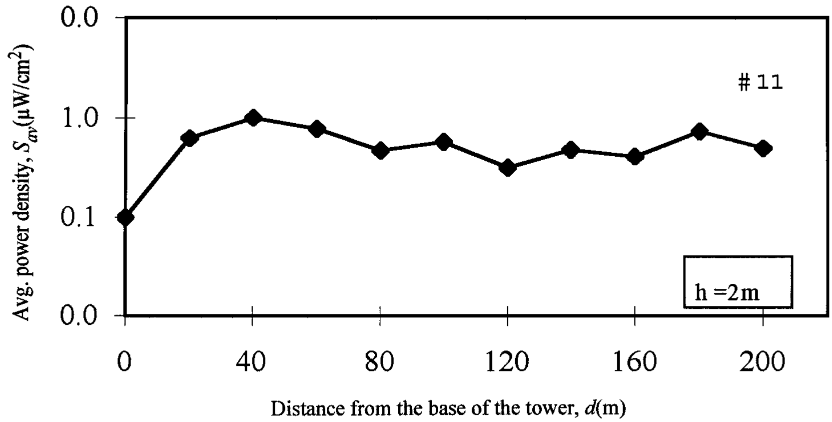

FIG. 6. Variation of average power density S_{av} (μW/cm^2) with distance d (m) from base Station ZRYA 11.

The variation of S_{av} versus the distance d from the tower of base Station ZRYA 23 is shown in Fig. 7. In this case, the antennas are installed on a rooftop of a commercial building of about 30 m height. The measurements are carried out across the road in front of the antennas and just at the entrance of the commercial center. Generally, the power density increases with distance increase from about 0.02 μW/cm^2 inside the building to about 0.5 μW/cm^2 at a distance of 100 to 120 m, then starts to decrease afterwards to about 0.2 μW/cm^2. However, again fluctuation of the power density is evident as before, which may be due to multiple reflections in this commercial area environment. The signal attenuation due to the building is about 13 dB.

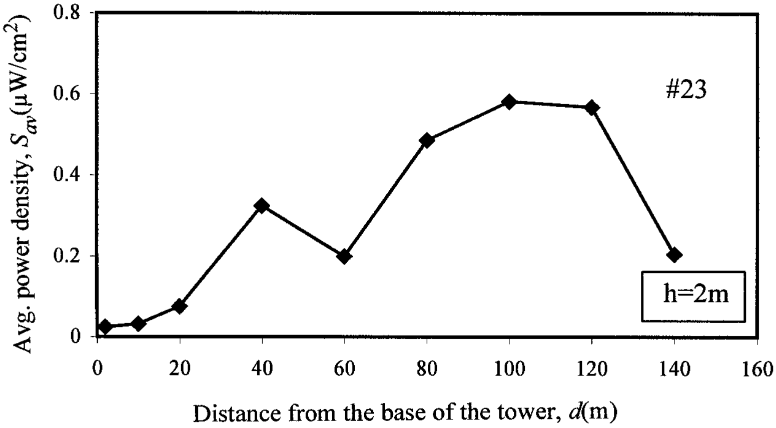

FIG. 7. Variation of average power density *Sav* (µW/cm2) with distance *d* (m) from of base Station ZRYA 23.

To study the variation of the electric field E with distance near the tower of the base stations, the field in $E(dB^{\mu}V/m)$ is plotted versus ($log\ d$), in the far field region. Regression analysis is employed to find a linear fit model to the data as shown in Fig. 8. It can be seen that $E(dB^{\mu}V/m)$ versus ($log\ d$), near the base stations and in the far field region for 40 m > d > 200 m, can be represented as:

$$E(dB^{\mu}V/m) = 127.59 - 1.97\ log\ d\ (m) \quad \text{for base Station ZRYA 41} \tag{3}$$

$$E(dB^{\mu}V/m) = 126.72 - 1.41\ log\ d\ (m) \quad \text{for base Station ZRYA 106} \tag{4}$$

$$E(db^{\mu}V/m) = 131.14 - 3.93\ log\ d\ (m) \quad \text{for base Station ZRYA 11} \tag{5}$$

A linear model could not fit the measurements of the electric field near the base station #23 with distance. This may be attributed to the urban and relatively dense environment of this site, which is characterized by multiple reflections, diffraction and scattering from nearby high buildings.

Generally for all the base stations, it is found that the power densities are relatively low at the foot of base station tower ($d \leq 5$ m), where it is ≤ 0.15 µW/cm^2, and increase with distance increase from the tower. This is in agreement with the measurements by Peterson Testagrossa[2]. The maximum measured power density near the base stations, at 2 m height above the ground, is on the order of about 1 µW/cm^2. But it increases with the height increase to about 1.4 µW/cm^2 at 2.6 m above the ground. Generally, this measured maximum power density is far below the Maximum Permissible Exposure Limits (MPEL) of the standards and guidelines for public exposure[3-9]. It is about 0.3% of the FCC or the ANSI/IEEE or the Japanese standards, 0.4% of the CENELEC or IRPA or Finnish standards, and about 14% of the Russian standard.

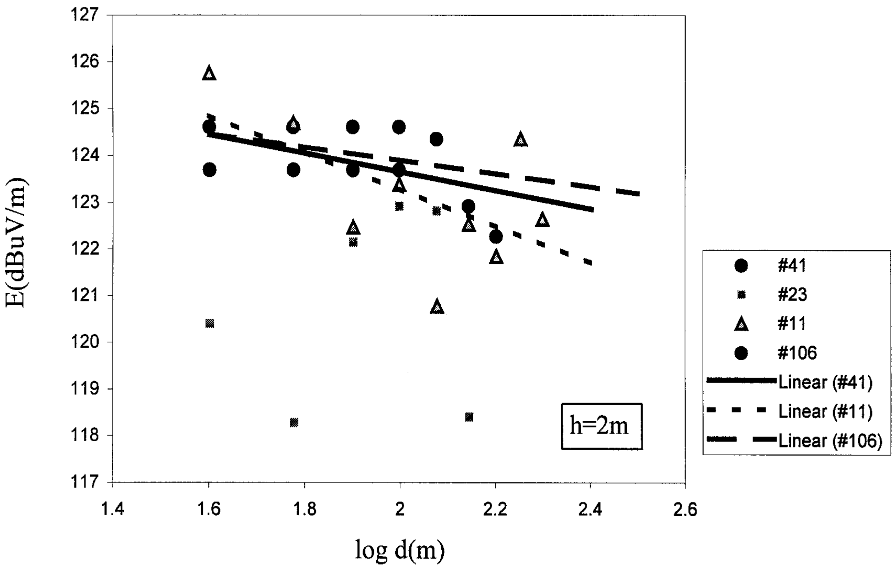

FIG. 8. Fitting E ($dB^{\mu}V/m$) versus *log* (*m*) for plane wave conditions. A linear model can represent only base stations #041, #011, and #023.

4. Conclusions

The RF radiation from the antennas of base stations of cellular mobile radio operating in the 870-906 MHz band and with a total EIRP of about 53 dBm was evaluated. The chosen base stations were located in urban as well as suburban areas of a big city.

The measurements show that the maximal power density at a level of 2 m above the ground level was about 1.4 μW/cm^2. The variation of power density with height (and within 3 m) above the ground level is linear. At distances greater than 40 m from the base stations the measured average power density was found to be almost steady at 1 μW/cm^2 within the suburban areas while it was fluctuating between 0.2-0.6 μW/cm^2 within the urban areas. This measured maximum power density is far below the maximum permissible exposure limits of most of the well-known RF safety standards which ranges from 0.2-1.2 μW/cm^2.

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قياس المجـال الكهرومغناطيسى قريبًا من المحطـات القاعديـة الخلويـة للهاتف الجـوال

عبدالعزيز بن سالم الرويس
قسم الهندسة الكهربائية ، كلية الهندسة ، جامعة الملك سعود
الريـــاض – المملكة العربية السعودية

المستـخلص . تبـحث هذه الورقـة في مسـتـويات الإشـعـاع الكهـرومغناطيسي التي يتعـرض لـها الجـمهـور والمنبعـثـة من المحطات القاعـدية للهاتف الجوال . فقد تم قياس كثافة القـدرة حول هذه المحطات القـاعـدية في داخل مـدينـة الرياض وفي ضـواحيـهـا وبلغت أقـصى قـيـمة لكثافة القـدرة حـوالي ٤ , ١ مللي واط/ سم^{٢} على مستوي يرتفـع ٢ متر فـوق سطح الأرض . وقد تبين أن كـثافة القـدرة تتغير خطيًا مع الارتفاع فـوق سطح الأرض في المدى المحصـور بين ١ إلى ٣ أمتـار . أما متـوسط قيـمة كثافة القـدرة المقاسة فقد بلغ حوالي ١ ميكروواط/ سم^{٢} . أما تغير كثافة القدرة مع المسافة عن المحطة القاعدية فقد كان ثابتًا تقريبًا في منطقة ضواحي مدينة الرياض ، بينما كـانت تتراوح بسرعة خلال المدى من ٢ , ٠ إلى ٦ , ٠ مـيكروواط/ سم^{٢} في داخل مـدينة الرياض ، وذلـك خـلال المسافات التي تزيد عن ٤٠ متراً من المحطة . وعليه فإن القيم المقاسة أقل من حدود الأمان المعتمدة حاليًا .