JKAU: Met., Env. & Arid Land Agric. Sci., **Vol. 25** No. 2, pp: 51-65 (2014 A.D./1435 A.H.)
DOI: 10.4197/Met. 25-2.4

Power Density of Cellular Tower Against Distance, Direction and Height: A Case Study

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Abstract. The present study aims to evaluate the power density levels emitted from a cellular phone tower at different horizontal distances and heights, in Al-Madinah Al Munawwarah, Saudi Arabia. A portable meter TES 593 was used to measure the power density levels. Specific absorption rate was calculated from the measured levels. The maximum average power density levels ranged between 0.234 mW/m^2 and 4.912 mW/m^2. The highest levels were found within 40-50 m in south and north, and 160 m in west and east directions. The exposure levels were below the international commission on non-ionizing radiation protection (ICNIRP) limit and above the limit values recommended by some countries ($\leq$ 1 mW/m^2). The maximum power density ~ 24.3 mW/m^2 was found at 11 m height, and 60 m distance from the tower. The levels reduced by ~ 58.76 % and 99% at 8 m height, 40 m and 60 m distances from the tower, respectively. Specific absorption rates (SARs) were below the international limit value (2 W/kg). The highest SAR value constituted 0.4% over the ICNIRP limit value, for 1800 MHz. The power density levels significantly varied with distance, direction, and height; these factors should be taken into consideration for determining the safety of a place.

Introduction

Wireless technologies are ubiquitous today, but require an extensive infrastructure. From 1990 to 2011, worldwide mobile phone subscriptions grew from 12.4 million to over 6 billion, about 87% of the global population, reaching the bottom of the economic pyramid (GMS, 2012, Michael, 2012). In some developing countries, cellular technology is the fastest growing segment of many economies (Levitt and Lai, 2010). Cellular facilities use a few hundred watts of effective radiated power (ERP) in comparison with other commercial uses of radiofrequency energy such as, wireless transmission for radio, television, satellite, police and military radar. Radio-frequency radiation (RFR) is present at all times within the environment (Beg, *et al*., 2010).

Exposure to RFR causes some biological changes in animals and birds (Balmori and Hallberg, 2007; Balmori, 2010). Scientific reports and epidemiological studies have found headache, skin rash, sleep disturbance, depression, decreased libido, increased rate of suicide, concentration problem, dizziness, memory change (Khurana, 2010), and increased risk of cancer in populations near base stations (Maier *et al*., 2003)

In view of the possible harmful effects of RFR on the biological systems, the International Commission on Non-Ionizing Radiation Protection (ICNIRP) and the Institute of Electric and Electronic Engineers (IEEE) and the Federal Communications Commission (FCC) have published standards for the RFR exposures (Santini, *et al*., 2003). The standards are currently based on RFRs ability to heat tissue and their thermal effects (Levitt, 1995).

It is well known that the levels of RFR decrease as increasing distance from the tower, and the location facing the tower antenna has much radiation than one on the back side (Al-Ruwais, 2001). For high antenna position, 50 – 90 m, the maximum power at ground level is reached in ~ 300 m, and for low antenna position, 15 – 20 m, is reached in ~ 50 m (Haumann, *et al*., 2002). The sitting of cellular phone base stations and other cellular infrastructures in residential neighborhoods is a contentious subject, as fears of adverse health effects, and confidence of the public (Levitt, 1998).

Until now limited data base is currently available on power density levels coming from the cellular phone towers in Al-Madinah Al Munawwarah city, Saudi Arabia. This city is a unique as it is extremely barren, sparse population, and rich. Moreover its geographical and meteorological features differ from other cities that have been evaluated for RFR in literature. The present study aims to evaluate the power density levels at various horizontal distances in the main directions. In addition to evaluate the power density levels at different heights inside and outside a residential building, in the same direction of tower antennas, in order to collect data on electromagnetic radiation to make up the gap of information lack on RFR in the city, and determine safety of RFR exposures to those who live near the cellular towers.

Materials and Methods

Sampling Site

The sampling site was chosen at Al-Jamawat district. It is located nearby Taiba University ~ 4 Km west of Al Haram Mosque, Al-Madinah Al Munawwarah (Fig. 1).

Fig. 1. Map shows a building with the mobile tower on the roof, and sampling distances.

The measurements were taken at various horizontal distances: ≤10 m; 20 m; 30 m; 40 m, 50 m; 60 m; 80 m; and 160 m at the main directions (North, South, East and West). Moreover, measurements were taken at different heights, 11 m; 8 m; and 5 m at 40 m and 60 m distances, in the same side of the tower antennas. The mobile phone tower is located in an open area, in particular, in the west direction with no other towers within the area (Fig. 1).

The antenna is mainly oriented to east-south direction and the measurements were conducted between 3 to 6 pm, during the period from 1st to 30th October 2013, month of Hajj, where millions of Muslims visit Al-Madinah Al Munawwarah.

Sampling Instrument *and* ***Parameters***

Power density and specific absorption rate (SAR) are used to determine radiation exposure levels. The power density measurements were performed using a portable instrument, TES 593 electro-smog meter (TES Electrical Electronic Corp., China). The TES 593 meter covers a wide range of frequencies, 10 MHz to 8 GHz, and is sensitive to detect field < 0.0001 mW/m^2. It is non-directional (isotropic) measurement with three-channel measurement probe (sensor). The instrument was allowed to stabilize for 1 to 2 min, before readings were recorded in the maximum average mode. The TES 593 meter was positioned at a height of 1.5 m from the ground level, the head zone of most people. The power density measurements were recorded in milliwatt per square meter (mW/m^2).

SAR is described as the transfer of energy from electric and magnetic fields to charged particles in an absorber. SAR was estimated at a point on the brain as the absorber, and SAR is related to electric field through the following equation (Ghandi, 1990).

$$SAR = \sigma \, |E^2| \, / \, Pm \qquad (1)$$

where:

σ: Conductivity of the human brain tissue

$|E^2|$: Magnitude of electric field vector (RMS, root mean square)

p_m: Mass density of the human brain tissue

The electro-smog meter shows power density values in both mW/m^2 and V/m, and these values are used to estimate SAR. The conductivity and mass density values for frequencies 900 and 1,800 MHz are showed in Table 1 (Dhami, 2012).

Table 1. Tissue dielectric properties for the human brain.

Frequency/ MHz	Conductivity/ $ohm^{-1}\ m^{-1}$	Mass density/kg/m^3
900	0.7665	1030
1800	1.1531	1030

Statistical Analysis

The Mann–Whitney U test was used to ascertain the significance of differences between power density measurements at the different distances, in the all direction. A probability of less or equal to $P \leq 0.05$ was considered significant. Percentile was determined using excel program-Window 7.

Results and Discussion

Power Density Levels as a Function with Distance and *Direction*

The power density levels ranged between 0.234 mW/m^2 and 4.912 mW/m^2, with the highest levels were found within 40 - 50 m, in the south and north directions, and 80 - 160 m in the west and east directions (Fig. 2). The levels fluctuated with increasing distance in the south, west and north directions, however it steady increased as increasing of distance in the east direction.

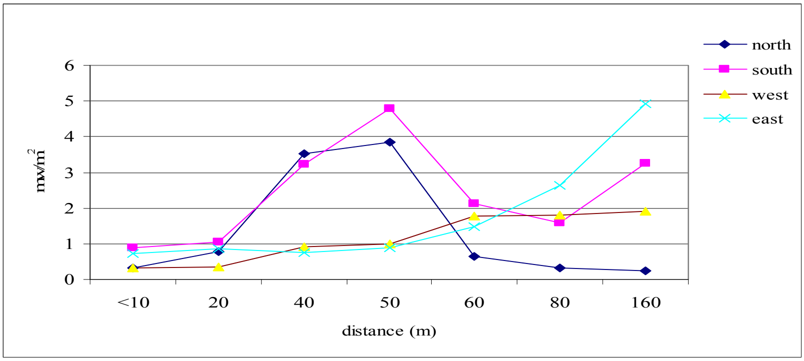

Fig. 2. Power density levels against horizontal distances in the different direction.

The highest power density levels were found at 50 m in the south direction (4.79 mW/m^2), and at 160 m in both the east (4.91 mW/m^2) and west (1.9 mW/m^2) in the face and back sides of the antenna, respectively (Fig. 3). This can be explained by the influence of antenna direction and position as the maximum radiations are shifted to larger distances. Dhami (2012) reported that the areas located on the back side of the antenna gave lower power levels than the ones facing antenna, thus, only being close to antenna does not make it as hazardous zone as being both close and facing it. In the present study, the fluctuation of the power density levels with distance and direction is attributed to the effects of obstacle and direction of antenna.

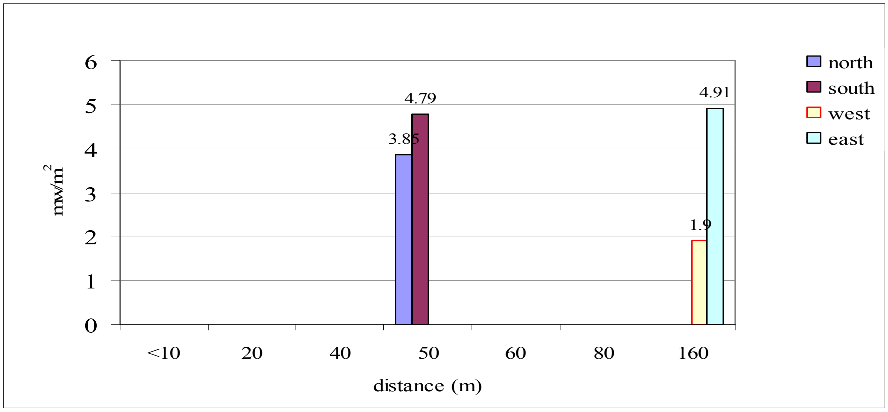

Fig. 3. Maximum power density levels against horizontal distance in different directions

Statistical Data and Percentiles

Statistical differences between power density levels at the similar distances in the different directions are illustrated in Table 2. There were significant differences between power density levels measured at 40 m in the south with all other directions. The levels in the south, west and east directions significantly differed from those measured in the north (low levels shifted to the north).

The percentiles of the power density levels are presented in Figure 4. The 20th percentile ranged between 0.296 -1.1019 mW/m^2, and can be considered as a background radiation level. The 50th percentile (median) ranged between 0.641 mW/m^2 in the north and 2.041 mW/m^2 in the south direction. The 95th percentiles were 4.071 mW/m^2; 2.168 mW/m^2; 6.901 mW/m^2 and 4.336 mW/m^2 in the north, west, south and east, respectively. The highest level was found in the south direction and can be considered as significant exposure.

The Power Density Level against Height

Figure 5 shows the variation of the power density levels against height. The power density level increased with height and reached its maximum value ~ 24.3 mW/m^2 at 11 m height, and horizontal distance

Table 2. The degree of significance of difference between power density levels at the different distances in all directions using Mann Whitney U test.

Direction/ distance	North				West				East			
	distance (m)				distance (m)				distance (m)			
	40	60	80	160	40	60	80	160	40	60	80	160
South												
40	0.053				0.016				0.028			
60		0.004				0.111				0.534		
80			0.05				0.571				0.243	
160				0.0143				0.50				0.343
East												
40					0.17							
60						0.443						
80							0.0143					
160								0.004				
North												
40					0.001				0.001			
60						0.004				0.004		
80							0.05				0.05	
160								0.0143				0.0143

Significant (P<0.05)

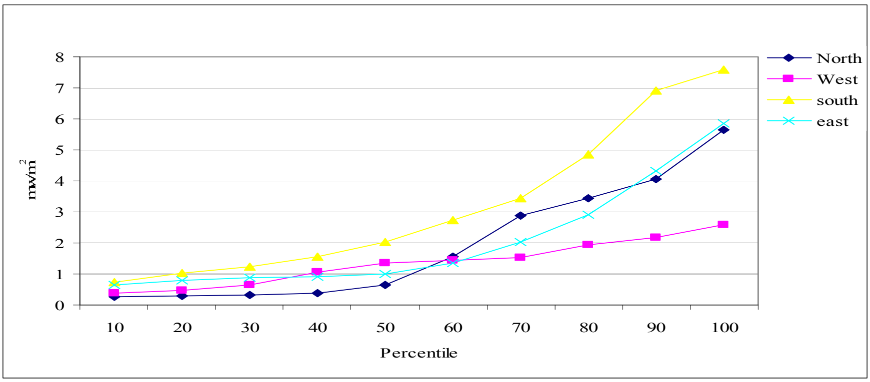

Fig. 4. Mobile power density levels versus percentiles in the different directions.

of 60 m. Surprisingly, lower power density level (13 mW/m^2) was measured at the same height but nearer to the tower 40 m (Fig. 5). The power density levels were reduced by 58.76 % and 99% at the height of 8 m; at 40 m and 60 m distances, respectively, and reached ~ 99 % at 5 m height, but inside a residential building in the same direction of the antenna. This confirms that the distance, height, direction of the antenna, and presence of obstacles control power density levels. Haumann *et al.* (2002) found the highest power density levels in the range of 10 – 100 mW/m^2 close to low antenna / roof top positions, at inside and outside locations in the line of sight and a distance < 100 m. They also reported that radiation exposure is determined by distance and line of sight to the antenna site, number and orientation of the antennas, types and directions of antennas, vertical distance between location and antenna site, and total reflection of the environment. Therefore by analyzing RFR pattern of a cell tower antenna, it is well known that the main beam propagates horizontally with high power zone ~ 50-300 m and the radius of the beam becomes wider with extending distance from the tower, but with lower power zone. In addition, low power zone is found in the vertical direction close to the phone tower and this confirms the findings in the present study.

The power density levels in all directions and distances were many orders of magnitude lower than the allowed exposure levels established by different regulatory organizations (ICNIRP, 1998; FCC, 1997; ANSI/IEEE, 1999); however the power density levels exceeded the limit values that are adopted by some countries (Table 3).

Specific Absorption Rate

Specific Absorption Rate (SAR) is the rate of energy that is actually absorbed by a unit of tissue, and it is more accurate than the power density measurements. Specific absorption rates (SARs) are generally expressed in watts per kilogram (W/kg) of tissue. Absorption of RFR depends on many factors including the transmission frequency and the power density, one’s distance from the radiating source, and one’s orientation toward the radiation of the system, as well as the size, shape, mineral and water content of an organism (Wiart, *et al.*, 2008, Levitt and Lai, 2010).

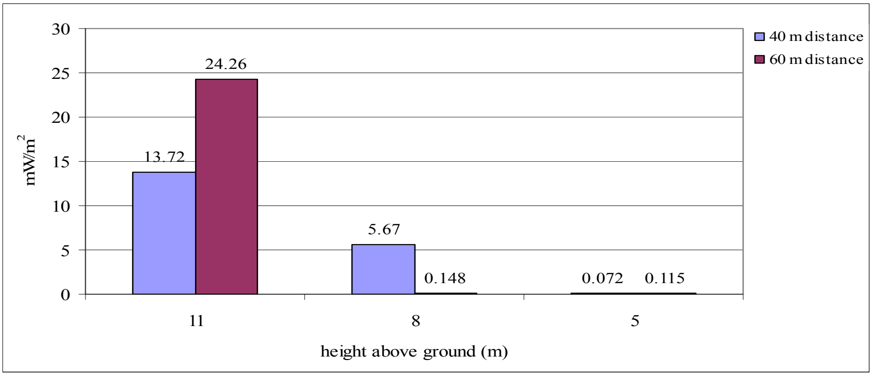

Fig. 5. Power density levels versus both the height and horizontal distances.

In the present study, SAR reached 0.019 W/kg at 160 m distance in the south direction, for 1800 MHz, as well as 0.004 W/Kg and 0.008 W/Kg at 11 m and 8 m heights. The SARs were ~100 and 1000 time folds lower at 5 m height than those at 11 and 8 m heights, respectively. SARs are many order of magnitude below the limit values allowed by the international boards, 1.6 W/kg (FCC, 1997), and 2 W/kg (ICNIRP, 1998) for 1800 MHz.

The maximum SAR (1800 MHz) 0.019 W/kg was found at 160 m in the south direction, and constituted 0.95% over the limit value of 2 W/kg (ICNRP, 1998), and 0.2% and 0.4% over the limit values, 11 m height at 40 and 60 m distance, respectively.

Table 3. International Exposure limit values for RF fields at 1800 MHz

Exposure limits for RFR, mW/m²	
9500	ICNIRP (1998)
10000	FCC (1997)
10000	ANSI/IEEE (1999)
10000	Canada-Safety Code-6 (2009)
2500	Belgium Guidelines (Nov, 2001)
100	Poland, China and Russia (Foster, 2001).
10.0	ECOLOG Institute – Germany (2000)
95	Switzerland (NISV, 1999).
1.00	Precautionary limit in Austria, Salzburg City only (Oberfeld and Konig, 2000)
0.01	Salzburg GSM/3G outside houses (HDFSS, 2002a)
0.001	Salzburg GSM/3G inside houses (HDFSS, 2002b)
20.0	Russia, Bulgaria, Hungary, sensitive areas (Stam, 2011)

The harmful biological effects start occurring in the brain at SARs as low as 0.001 W/kg (de Pomerrai, 2000), change in calcium concentration in heart muscle cells of guinea pigs (Wolke, 1996), increase in calcium efflux in human neuroblastoma cells after exposure to RFR at 0.005

W/kg (Dutta, *et al*., 1989), and increase in permeability of blood-brain barrier in mice at SAR level of 0.0004–0.008 W/Kg (Persson, 1997). Forgacs *et al*. (2006) reported an increase in serum testosterone levels in rats exposed to GSM (global system for mobile communication) like RFR at SAR of 0.018–0.025 W/kg. Kesari and Behari (2009) reported an increase in DNA strand breaks in brain cells of rats after exposure to RFR at SAR of 0.0008 W/kg. Biological effects do not automatically mean adverse health effects and many biological effects are reversible (Levitt and Lai, 2010). However, RFR is among the potential pollutants with an ability to adversely affect people, and the safety of the neighborhood cannot be accurately determined from this case study.

Conclusion

The power density levels coming from the cellular phone tower were measured in the main directions from the antenna started at ~10 m and repeated at interval locations until 160 m. The highest power density levels were found in the locations facing antenna and as high as the height of the tower. The presence of obstacles significantly reduced power density even locations in the line sight of antenna. The power density increased as increasing of horizontal distance from the tower, in absence of obstacles and in the direction of the antenna. The power density values were reduced ~99% from 11 m height to 5 m height. The power density levels were below the international limit values; however some levels exceeded the recommended limit values that are adopted by some countries 0.001-1.00 mW/m^2. SARs were much lower than the allowable 2 W/ kg, however some SARs exceeded the limit value, at which the biological effects begin, 0.001 W/kg. The cellular phone tower under investigation is considered safe. This work is an initial effort to determine RFR exposure levels in Al-Madinah Al Munawwarah city. The effects of environmental, topographical, and meteorological factors on the distribution pattern of RFR need to be studied in the future, including more comparison and contrasts with other locations and cities.

Acknowledgement

We are thankful to the Hajj Research Institute, Umm Al-Qura University Makkah, Saudi Arabia for sponsoring this study.

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كثافة الطاقة الكهرومغناطيسية لبرج الهاتف المحمول مع اختلاف المسافة الاتجاه والارتفاع: دراسة حالة

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المستخلص. يعتبر الإشعاع الكهرومغناطيسي الناتج من أبراج الهاتف المحمول أحد أنواع التلوث البيئي والذي يشكل خطرًا صحيًا، وهو مثير للقلق في أنحاء العالم نظرًا لتأثيراته غير المرغوب فيها على صحة الإنسان والنبات والحيوان، وتهدف هذه الدراسة إلى قياس مستويات كثافة الطاقة، الناتجة من برج المحمول مقابل المسافات المختلفة من 10 متر إلى 160 متر عند الاتجاهات الأربعة (الشمال والجنوب والشرق والغرب) وعلى ارتفاعات 1.5 متر إلى 11 متر من على سطح الأرض. تم استخدام جهاز TES-593 لقياس كثافة الطاقة ومنها تم حساب معامل الامتصاص النوعى ومقارنة كثافة الطاقة ومعامل الامتصاص النوعى بالمعايير العالمية. تخطت كثافة الطاقة معايير بعض الدول (0.1 mW/m^2) ولكنها أقل من المعايير المسموح بها من قبل المنظمات والهيئات العالمية التنظمية، وكان معامل الامتصاص النوعي أقل من المعايير العالمية (2 واط/كجم)، وإن وصل إلى الحدود التي تبدأ عندها التأثيرات البيولوجية، سجلت كثافة الطاقة مستويات مرتفعة عند ارتفاع 11 متر على نفس خط البرج في اتجاه الهوائي، بينما انخفضت بنسبة تتراوح 90٪ على ارتفاعات أقل (8–5 متر) داخل المبنى وفي نفس

اتجاه الهوائي حيث إن العوائق وعدم تجانس البيئة أدى إلى اختلاف نمط توزيع كثافة الطاقة الكهرومغناطيسية. سجلت أعلى مستويات في اتجاه هوائي المحمول في اتجاهي الشرق والجنوب، والأقل عند اتجاه الشمال، تم رصد أعلى مستويات لكثافة الطاقة عند 40–60 متر من البرج، أما في المناطق المفتوحة فكانت عند مسافة 160 متر. ومن ثم فإن قياس المسافة من البرج ليست بالوسيلة التي يمكن الاعتماد عليها لاعتبار المكان آمن أو غير آمن ما لم يتم تحديد الاتجاه والارتفاع كذلك.