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Radio frequency radiation measurement for base tower station safety compliances: a case study in Pulau Pinang Malaysia

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ABSTRACT

The residence of Pulau Pinang and Malaysia generally are worried with the possible health effects due to Base Tower Station (BTS) radiation. Particularly, the residents of Pulau Pinang are utilizing their mobile phones for multiple kind of tasks including communications, browsing the internet and other applications. With the recent advances in mobile communication technologies, the end user demanded a better coverage, great communication services, and faster speed for internet browsing. To fulfill the demand, service provider and communication companies are providing plenty of communication base tower leading to the beliefs of that the tower emitted radiation and cause harmful effect to human health and voiced out and complain to the municipal councils in Malaysia. In this paper, a measurement was conducted to study electromagnetic fields (EMF) radiation level in Pulau Pinang. The measurement is compared with the international standard provided by International Commission of Non-Ionizing Radiation Protection (ICNIRP). Far field measurement of different values of long term evolution (LTE) exposure was demonstrated in radiofrequency (RF) shielded environment. LTE850, LTE1800 and LTE2600 field exposure was compared in term of its' electrical field and power density that adhere to the standard provided by ICNIRP.

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1. INTRODUCTION

The Malaysian Communication and Multimedia Commission (MCMC) is a government body which responsible to prescribe the guidelines on permissible exposure levels of EMF/Microwave radiation for general public in Malaysia that strictly follows ICNIRP for human (public) safety from radiation of far field BTS exposure. However, Maximum Permissible Exposure (MPE) limits is varied and depended on the electromagnetic frequency operation. In this study, electrical field strength (E), an electric field (E) exerts forces on an electric charge and is expressed in Volt per meter (V/m) [1] is the derived quantity used for the reference level which is measured in V/m unit and (W/m^2) [2]. Authors in [3] has characterized exposure into occupational exposure and general public exposure. Occupational exposure refers to the workers whose aware of the microwave exposures' potential risks. The workers are exposed simultaneously to EMF of multiple frequencies ranges, different temporal variations and field strength [4]. In the other hand, public exposure refers to the individuals with no knowledge and control on microwave exposure. However, the guidelines for EMF from the authorities are set to avoid adverse health where public are present [4].

The Local authorities in Pulau Pinang (Majlis Perbandaran Pulau Pinang) is experiencing difficulties in giving the information to the residence in Pulau Pinang about mobile phone and telecommunication base tower that adhere the guidelines provided by the International Commission of Non-Ionizing Radiation Pattern (ICNIRP). It is also safe for human health due to the permissible exposure limits with respects to electromagnetic frequency strictly follows to the Federal Communication Commission (FCC), IEEE, and ICNIRP itself [5, 6]. The enhancement of the information sharing has been made by many of the representatives of Malaysian Communication and Multimedia Commission (MCMC) to the people of Pulau Pinang regarding the safety of telecommunications base stations and mobile phones. However, the public are partially believed to the talks and seminars.

Majlis Perbandaran Pulau Pinang (MPP) has presented the safety exposure guidelines and the actual exposure values to the society. In the other hands, the myth of harmful effects from BTS and mobile phones exposure which turns to be carcinogenic to human [5]. It is also being circulating around to the public, hence rises public concern regarding plenty of radiation sources [2, 6-8]. Thus, the collaboration of the Universiti Malaysia Perlis (UniMAP) and Fokus Murni Sdn. Bhd that play the important role of mediator are to provide the knowledge and depth in understanding the safety compliances of places nearby BTS. In this experiment, six considered location was selected based on the accessibility of an area to do the measurement. The measurement of RF radiation takes place in indoor condition. The experiment was then tested on the same operating frequencies in outdoor case study. It was aimed to compare the outcomes of both tested condition. The experiment was measured in term of electrical field and power density for all of the tested frequencies. The power density defined as the rate of flow of electromagnetic energy per unit area and expressed in watt per meter square (W/m^2). The power density, P_d of the equivalent plane wave is generally expressed as:

$$P_d = \frac{1}{2}.\,\mathrm{Re}[\bar{E} \times \bar{H}] \tag{1}$$

$$P_d = \frac{|\mathrm{E_{rms}}|^2}{\mathrm{Z_0}} = \mathrm{Z_0}.\,|\mathrm{H_{rms}}|^2 \tag{2}$$

where $\bar{E}$ and $\bar{H}$ are the electric and magnetic fields intensity of the electromagnetic waves, Z_o is the impedance of the free space.

$$Z_0 = \sqrt{\frac{\mu_0}{\epsilon_0}} \tag{3}$$

$$\mu_0 = 4\pi \times 10^{-7}\ \mathrm{H/m} \tag{4}$$

$$\epsilon_0 = \frac{10^{-9}}{36\pi}\ \mathrm{F/\ m} \tag{5}$$

then Z_o=120π ≈ 377 Ω.

The magnitude of the far field radiated by the base station antenna system is determined by using ray tracing algorithm based on the geometrical optic method [9-10]. The calculation of equivalent P_d can be calculated by using the following formulas and assumes field impedance, Z_o.

$$P_d = 0.0796N\frac{P_{rad}}{R^2} \times 10^{\frac{\mathrm{G}(\emptyset,\theta)}{10}} \tag{6}$$

where; N is the number of carriers,

P_{rad} is the radiated power in (W) emitted by the base station antenna.

$G(ø,\theta)$ is the antenna gain in (dB) in the direction where the person is placed relative to the antenna. The application when one person is exposed to one base station antenna (N=1) at its simplest case is shown in the Figure 1.

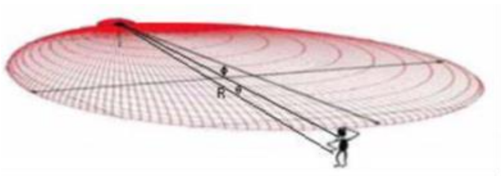

Figure 1. A person is exposed to one base station antenna [9]

In the case of multiple number of N antennas, total power density is obtained as the sum of individual P_d from each antenna in the point of interest. This is the simplest way to estimate the far field base station exposure [10]. Table 1 shows Maximum Permissible Exposure (MPE) reference levels for public exposure [1].

Table 1. Maximum Permissible Exposure (MPE) reference levels for public exposure [1]

	Signal Frequency (MHz)			
	2G	2G	3G, Wireless Broadband	Wi-Fi
Derived Quantities	900	1800	2100	2400
E-field Value (V/m)	41.25	58.3	61.5	61
Power Density (W/m^2)	4.5	9	10	10

2. MEASUREMENT SETUP
2.1. Indoor measurement

The measurement was carried out in a RF-shielded room anechoic chamber which takes 2.4 m, 3.7 m and 2.47 m with respect to width, length and height with total surface area of 41.96 m^2, as shown in Figure 2. The directional antenna was placed approximately 1.5m from ground in order to record the measurement [8]. It represents the head position of average adults which resembles the experimental procedure in [2, 8]. The measurement time of six minutes was carried out as in the standard recommended by ICNIRP and IEEE [1, 7] to ensure the data acquired is accurate. Maximum value of electrical field strength is recorded to compare the compliances level of human exposure to radiation.

The instrument to conduct the experimental measurement was the Rohde & Schwarz (R&S) FSH4-Handled Spectrum Analyzer (SA) featuring operating frequencies at 9 KHz to 3.6 GHz, as shown in Figure 3. The utilized instrument is able to measure a wide spectrum of electromagnetic field which is in electric field strength (V/m) for this research. It has a wide frequency ranges covering every common radio services such as Global System for Mobile Communication (GSM), Bluetooth, Wireless Fidelity (Wi-Fi), and Frequency Modulation (FM) radio. Next, R&S Signal Generator (SG) model SMBV100A, base-station antenna and far-field EMF active directional antenna model R&S HE300 as the receiver. The far field distance required to generate a base station-like signal is calculated by:

$$d=2D^2/\lambda \quad (8)$$

where D is the largest dimension of the source of the radiation. Table 2 presents the far field distance of each measured frequencies. Table 3 presents the instruments and type of probes used in the indoor measurement.

Table 2. Far field distance for LTE 850, LTE 1800 and LTE 2600 MHz

Frequency, f (MHz)	Wavelength, λ (m)	Far-field Distance, d (m)
850	0.3529	0.2869
1800	0.1667	0.6075
2600	0.1154	0.8775

Table 3. Instruments and type of probes used in the indoor measurement

Instruments	Frequency Range
RS handled spectrum analyzer model (FHS4)	9 kHz-7.5 GHz
R&S EMF Probe antenna (far-field) model HE300 antenna module 4067.6458.00	500 MHz–3.6 GHz

Figure 2. RF-shielded room for indoor measurement setup

Figure 3. Antenna setup for far field BTS radiation exposure

2.2. Outdoor measurement

The RF radiation level was carried out in six locations which denoted as 1st Location to 6th Location. The measurement sites were selected based on the rate of population and concerned areas i.e. the closest populated area with the BTS (1st Location) and the farthest populated area with the BTS (6th Location).

Instrumentation exposure was set up to an electromagnetic field distribution that emulates the far field of a base station was measured to ensure that the power received by each of the subject is set to 1 V/m, both from LTE 850, LTE 1800 and LTE 2600 field exposure. The signal generator was connected to the far field EMF probe antenna, as shown in Figure 3.

According to [3], there are two methods to determine the MPE emit from the base tower. Firstly, RF/EMF radiation can be measured by simulating the antenna from the base tower. The technical information and relevant specification is needed to simulate the exposure. Secondly, the approach proposed in this research, a direct measurement of RF radiation exposure from the base tower at any concerned location is recorded through the appropriate instrument, as shown in Figure 4. The nearest distance for the base station and the receiver follows International Telecommunication Union (ITU) recommendation which is explained in [11, 12].

3. RESULTS AND ANALYSIS

To compare the recorded data with the compliance value according to ICNIRP and MCMC standard, the highest peak recorded is considered. For this research purpose, four types of signals were considered at each location i.e. 900 MHz, 1800 MHz, 2.1 GHz, and 2.4 GHz.

In general observation, the maximum recorded level of electrical field strength is very low at every location. It can be categorized as conform the ICNIRP and MCMC public safety standard. The antenna is acting as receiver to receive the RF signal from the base tower. It shows the presence of radiation as displayed by spectrum analyzer at each location for every signal frequency. As each location gives a different distance, the electrical field strength recorded is also varied.

3.1. Results of indoor measurement

Figure 5 indicates E-field and power density receive outcomes from LTE850, LTE1800 and LTE2600 exposure obtained from the spectrum analyzer. The result shows that E-field is set at 1 V/m for LTE850 signal exposure in the shielded room contributes to the radiation level at 0.0027 V/m^2 that corresponds to 0.006% exposure limit which is lower than exposure limit governed by ICNIRP for public as in Table 4. Meanwhile, E-field intensity for both LTE1800 and LTE2600 signal exposure is also set to 1 V/m which leads to radiation exposure of 0.0027 W/m^2 and 0.0028 W/m^2 respectively. Thus, it corresponds to 0.03% exposure limit lower than stated public exposure limit by ICNIRP for LTE1800 and LTE2600.

Table 4. Comparison of measured electrical field to exposure limit for LTE850, LTE1800, LTE 2600 with the limit recommended by ICNIRP

	Electric Field (V/m)			Power Density (W/m^2)		
	850MHz	1800MHz	2600MHz	850MHz	1800MHz	2600MHz
Receive value	1	1	1	$2.7x10^{-3}$	$2.7x10^{-3}$	$2.8x10^{-3}$
Exposure limit for public	40.1	58.3	70.1	4.25	9	10
Comparison with exposure limit (%)	0.002	1.71	1.43	0.06	0.03	0.03

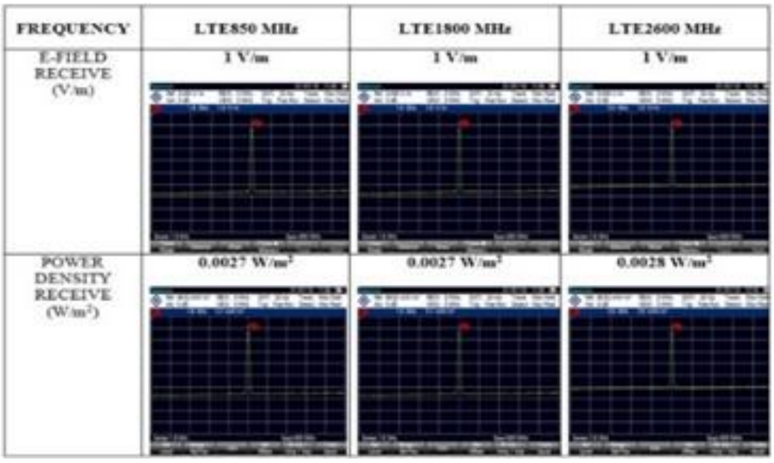

Figure 5. Far-field distance of base station electrical field strength for LTE850, LTE1800, and LTE2600 field exposure

3.2. Results of outdoor measurement

The highest electrical field strength recorded for second generation mobile network (2G) is at 942 MHz for 0.369 V/m (0.89% from permitted standard) for the shortest distance. The lowest electrical field strength recorded is 0.027 V/m at the farthest location, the same for 1800MHz, the highest electrical strength is recorded at shortest distance for 0.19 V/m (0.33% from permitted standard). The highest electrical field strength recorded is 0.5 V/m (0.82% from permitted standard). The value is for third generation mobile network (3G) service and measured at 1st location. For Wi-Fi services, the highest value recorded is 0.16 V/m (0.26% from permitted standard) at 3rd location.

Table 5 and 6 indicate each measured signal for different 2G operating frequencies, 900 MHz and 1800 MHz, respectively. The measured electrical field strength varies as low as 0.01 V/m to the highest value of 0.369 V/m of MPE for public exposure. The measured electrical field strength is at its highest for the receiving antenna which is placed near to the BTS. In contrast, measured electrical field strength is at its lowest for the antenna that is placed far from the BTS. However, in some location i.e. Location 5th, it does not follow the rule of thumb which has several theoretical possibilities lead to the causes. Theoretically, the characteristic of microwave signals is that, it can be reflected, re-radiated, scattered, attenuated or absorbed by the material which permits the signal to occur in free space environment such as trees, walls and conducting structures. It may increase or decrease the electrical field strength in a location. Any unidentified signals that present from unknown or hidden transmitter may invite to the factor of microwave exposure level variations [3].

Table 5. Electrical field strength for 2G (900 MHz) signal

Location	Standard MPE (ICNIRP) (V/m)	Measured MPE (V/m)	Exposure Ratio Measured MPE with ICNIRP MPE (%)
1	41.25	0.369	0.89%
2		0.357	0.87%
3		0.244	0.59%
4		0.048	0.12%
5		0.241	0.58%
6		0.027	0.07%

Table 6. Electrical field strength for 2G (1800 MHz) signal

Location	Standard MPE (ICNIRP) (V/m)	Measured MPE (V/m)	Exposure Ratio Measured MPE with ICNIRP MPE (%)
1	58.3	0.190	0.33%
2		0.100	0.17%
3		0.050	0.09%
4		0.009	0.02%
5		0.023	0.04%
6		0.010	0.02%

Table 7 indicates measured electrical field strength for 3G at 2100 MHz operating frequency. The values of each location vary and fluctuate from location one until location six. The lowest value recorded was 0.0245 V/m at location 4 whereas highest value recorded was 0.504 V/m at location 1. Measured electrical field strength for 3G was observed to deviate from the concept of distance against electromagnetic strength. The inconsistency of recorded electrical field strength for every location could be the same theoretical reason as in the case of Table 5 and 6. It can be reflected, re-radiated, scattered, attenuated or absorbed.

Table 7. Electrical field strength for 3G (2100 MHz)

Location	Standard MPE (ICNIRP) (V/m)	Measured MPE (V/m)	Exposure Ratio Measured MPE with ICNIRP MPE (%)
1	61.5	0.504	0.82%
2		0.245	0.40%
3		0.437	0.71%
4		0.027	0.04%
5		0.230	0.37%
6		0.032	0.05%

Measured electrical field strength particularly in Table 8 (2400 MHz, Wi-Fi) clearly indicates that most of the measured value are slightly low due to the operating frequency (2.4 GHz) which intents to deliver over short distance from 50 up to 150 meters at most [13]. Most of the Wi-Fi service operates for indoor purposes. However, the experimental measurement takes place in outdoors area. Apart from that, [14] has represented experimental measurement for Wi-Fi radiation in a public area which in turn to be inconclusive. There is no convincing scientific evidence that weak RF signals from wireless networks cause adverse health effects.

Table 8. Electrical field strength for Wi-Fi (2400 MHz) signal

Location	Standard MPE (ICNIRP) (V/m)	Measured MPE (V/m)	Exposure Ratio Measured MPE with ICNIRP MPE (%)
1	61.0	0.036	0.06%
2		0.034	0.06%
3		0.158	0.26%
4		0.014	0.02%
5		0.011	0.02%
6		0.010	0.02%

Electromagnetic waves in general have different specifications, according to their frequencies which bring different characteristics [15]. Electromagnetic spectrum in cellular communication system makes use of radio-frequency band of electromagnetic spectrum which generally use 900MHz and 2100MHz for 2G and 2100MHz for 3G. Besides, 4G utilizes 850MHz, 1800MHz and 2600MHz, plus 2400MHz for the Wi-Fi. Relating to this study, the concern about health hazard when implementing those technologies arises since electromagnetic exposures are emitted from the devices such as mobile phone, and base station. In this experiment's finding, the electromagnetic exposures in different operating frequency such as 2G, 3G and 4G are also varied in their readings which still fall far below MPE standard. In addition, authors in [16] suggest that for cellular network and base station to operate as intended without health effect, it is a must to comply with the safety guidelines relating to exposure of non-ionizing radiation. Moreover, GSM has claimed that their equipments comply with ICNIRP requirements [16].

4. CONCLUSION

The usage of mobile phone as a communication medium and information source are becoming ubiquitous in this era. It is to be understood that the radiation emitted from the antenna mounted on BTS is a type of non-ionizing radiation. There are invalid and insignificant evidence to support the claims that the radiation could cause adverse health effect to the human. A later case study performed by [13], [17] claims no concrete evidence on negative effects of health to the human among Malaysian. Besides, the findings in this research based on the indoor and outdoor measurement confirms that the level of E-field strength is very low. Furthermore, the finding in this research suggests that the usage of mobile phone from 2G, 3G, Wi-Fi for indoor and fourth generation mobile network (4G) outdoor is safe in term of the MPE. RF/EMF emitted from the BTS in Pulau Pinang will also be safe for the public, due to the radiation level at this particular location adheres to the permitted exposure limit.

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