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Calculation of SAR and Measurement of Temperature Change of Human Head Due To The Mobile Phone Waves At Frequencies 900 MHz and 1800 MHz

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Abstract: Today, cell phone technology is an integral part of everyday life and its use is not only restricted to voice conversations but also conveying news, high resolution pictures and internet. As the number of mobile phone usage increased exponentially nowadays, issues related to the electromagnetic radiation produce by mobile phone is becoming a big concern in the society. Mobile phone produced electromagnetic waves and when placed near the ear skull, will produce electromagnetic radiation so called thermal effect. The transfer of electromagnetic field to the body producing thermal effect leads to heating of body tissue at specific rate. This effect is differ depending on the period of time the mobile phone being used and type of mobile phone. This paper discussed on the result of thermal distribution generated by handheld mobile phone towards human head via collection of image from thermal imaging camera. The analysis is conducted in an anechoic chamber with average of 45 minutes talking hour with two different types of mobile phone, internal and external antenna serving different radio frequency range, 900 MHz and 1800 MHz . The results showed an increased of heat especially at the place near the ear skull after 45 minutes of operation. When comparing both different types of mobile phone, mobile phone with external antenna produce more heat compared to mobile phone with internal antenna.

Key words: Electromagnetic Radiation of 900 MHz and 1800 MHz Frequencies , Handheld Device, Thermal Effect, Non Thermal Effect

1. Introduction: In March of 1876 Alexander Graham Bell was awarded the first patent for an electronic telephone. Since that invention, the telephone has seen many technological advances. Touchtone phones, wireless hand-sets, car-phones, and most recently the cell phone and smart phones have all emerged in response to societies' needs and desires. Today, cell phone technology is an integral part of everyday life, and its use will continue to grow as providers proceed to offer more expansive services and newer, better products.

The number of mobile phone users has increased exponentially recently and it has become an important device in
human daily life. Estimates suggest there are around 1.6 billion mobile phone users throughout the world and the numbers are increasing [3]. Radio frequency used to communicate by mobile phone has the ability to penetrate through semi-solid substances like meat, and living tissue to a distance proportional to its power density [14]. It also can cause dielectric heating effect or thermal effect [3]. Thermal effects are the temperature rise in the body cause of energy absorption from oscillating electric fields or electromagnetic radiation [12]. Thermal radiation is generated when heat from the movement of charged particles within atoms of the mobile phone's case is converted to electromagnetic radiation (Wikipedia3, n.d.). Thermal radiation of the mobile phone also related to the specific absorption rate (SAR) where it is defined as the rate of radio frequency (RF) power absorbed per unit mass by any part of the body. SAR values are dependent on the separation distance of the body and the mobile phones. The nearer the distances of the radiation source to the human head, the higher the SAR values [9]. RF is emitted by the antenna of the mobile phone. An antenna is a transducer designed to transmit or receive electromagnetic waves [12]. There are commonly three types of antenna used in mobile phone application. Those three types are planar inverted F antenna, dipole antenna and monopole antenna. Planar inverted F antenna is formed by the modification of F antenna, dipole antenna is formed by conductors which separated by an odd number of half wavelengths long, while monopole antenna is designed by introducing a perfectly conducting flat ground plane into the equatorial plane of a dipole antenna [7].

Conducted studies have shown that RF radiation has the ability to cause biological damage through heating effects [2]. Besides that, non-specific complaints by mobile phone users on symptoms like headaches, earaches, blurring of vision, short term memory loss, numbing, itchy, burning sensations, bad sleep, electromagnetic hypersensitivity, exhaustion and anxiety also rise by the researcher [4]. Thermal effect has been reported to cause temperature rise at the skin near ear skull region while non-thermal effect would causes the cells to activate the third messenger systems, gene expression mechanisms and production of heat shock proteins in order to protect the cell from metabolic cell stress caused by heat. Mobile phone can also cause Deoxyribonucleic acid (DNA) damage. There were indications cell damage such as chromosomes damage, alterations in the activity of certain genes and a boosted rate of cell division. In 2004, the Swedish scientific team at the Karolinska Institute has reported that regular use of a mobile phone over a decade was associated with an increased risk of acoustic neuroma which is a type of benign brain tumor.
In Europe, the European Union Council has adopted the recommendations made by International Commission on Non Ionizing Radiation Protection. These recommendations set a SAR limit of 2.0 W/kg in 10g of tissue. The United Kingdom Government has endorsed this limit and five mobile phone network operators have agreed to voluntarily adopt the ICNIRP guidelines for public exposure [10]. All mobile phones on sale in the United Kingdom comply with this limit. In the United States, the Cellular Telecommunications and Internet Association (CTIA) requires all cell phones to comply with the Federal Communications Commission (FCC) SAR limit of 1.6 W/kg in 1g of tissue. These limits of the SAR level was establish to protect mobile phone user health from the mobile phone radiation.

2 Literature Review

2.1 Global System for Mobile Communication (GSM)

Global system for mobile communication (GSM) is a digital wireless communication protocol for mobile phones and was developed in the early 1980's.GSM technology is invented to eliminate certain problems with the predecessor cellular networks. The existing problems of cellular network are analog networks could not handle the growing capacity of cellular networks and the existing digital networks were not compatible with each other. GSM technologies had made the data communication easier to build into the system. It is a low-cost standard supported voice calls and short message service (SMS). GSM also provided useful features like security, authentication and the invention of the SIM card. GSM networks operate in four different frequency ranges which are 900 MHz band, 1800 MHz band, 800 MHz band and 1900 MHz band. GSM 900 and GSM 1800 standard is the most commonly used standard. 800 MHz band and 1900 MHz band is introduced because the 900 MHz and 1800 MHz frequency bands were already allocated. GSM 1800 standard provide more bandwidth and less power requirements than GSM 900 MHz . The transmission power in the mobile phone is limited to a maximum of 2 watts in GSM 800 and GSM 900 while maximum power of 1 watt in GSM 1800 and GSM 1900. The specifications of GSM 900 and GSM 1800 are shown in Table 1.

Table 1: Specification of the GSM 900 and GSM 1800

Specification	GSM 900	GSM 1800
Downlink Frequencies	935-960 MHz	1710-1785 MHz
Uplink Frequencies	890-915 MHz	1805-1880 MHz
Channel Spacing	200 kHz	200 kHz
Modulation	GMSK	GMSK
Typical Mobile Transmit Power	2W	1W
Maximum Base station transmit power	320W	20W
Maximum Distance	35 km	8 km
Speech Encoding	LPC (13 kbit)	LPC (13 kbit)
Bit rate	270 kbps	270 kbps

2.2 Radio Frequency and SAR

Radio frequency has the ability to penetrate through semi-solid substances like meat, and living tissue to a distance proportional to its power density. This ability will cause dielectric heating on the tissue of the human body. Dielectric heating also calls thermal effect. Thermal effects are the temperature rise in the body cause of energy absorption from oscillating electric fields. The force produced by an electric field on charged objects will generate electric currents.
Thermal effect from the high intensity radio frequency of mobile phone will cause heating at the skin near the ear skull region. Temperature at the skin will continuously increase until it is balanced at certain level when the heat will then be absorbed by the flow of blood to others part of body. Several minutes was taken for the radiated skin part temperature to reach the equilibrium temperature. The equilibrium temperature will be determined by calculating the average power absorbed which also called Specific Absorption Rate (SAR). Figure 1 shows the continuous of high intensity radiation of radio frequency toward the skin near the ear skull region [1].

Figure 1: High Intensity Radiation of Radio Frequency toward the Skin Near the Ear Skull Region

Specific Absorption Rate (SAR) is a dosimetric quantity which is defined as the rate of RF power absorbed per unit mass by any part of the body. SAR value commonly is determined either 1g or 10g of simulated biological tissue in the shape of a cube. SAR value normally specified at the maximum transmission power. Transmission power will be higher when the mobile phone is used at the area with very low field strength of received signals [9]. SAR values are dependent on the separation distance of the body and the mobile phones. As the distance of the body and mobile phones is closed, the SAR values will be higher and vice versa. Using mobile phones with low SAR values and making call at high reception field strength which permitting low transmission power can reduce the exposure to the high intensity radiation. Equation (1) shows the formula to calculating SAR.

$$SAR = \frac{\sigma[E]^2}{2\rho} = \frac{C\,\Delta T[W/kg]}{\Delta t} \quad \ldots\ldots\ldots(1)$$

From equation (1), σ is the conductivity of tissue simulant (s/cm), $|E|^2$ is the electric field strength (V^2/cm^2), ρ is the density of tissue simulant (g/cm^3), c is the specific heat capacity of tissue simulant (J/g/0C) and ΔT is the change in temperature when exposed for time change of Δt. The equation (1) also shown that SAR value can be determined from either electric-field amplitude or temperature measurement. SAR measurement always relate to the dielectric conductivity as shown in equation (1). Table 2 shows the electrical parameters of various tissues at different frequency.

Table 2: Electrical Parameters of Various Tissues [6]

No.	Tissue	Cells	ρ (g/cm^2)	Frequency			
				900 MHz		1800 MHz	
				εr	σ	εr	σ
1	Air	12360	…..	1.00	0.00	1.00	0.00
2	PEC	……	…….	……..	∞	….	∞
3	Bone	2188	1850	8.00	0.11	8.00	0.16
4	Skin/Fat	2318	1100	34.50	0.60	32.00	0.52
5	Muscle	3490	1040	58.50	1.21	55.00	1.70
6	Brain	4066	1030	55.00	1.23	53.00	1.70
7	Lens	8	1050	44.50	0.80	41.00	1.29
8	Cornea	108	1040	52.00	1.85	50.00	2.32

Thermal Effects
The tissue temperature increase resulting from exposure to EMW is referred to as "thermal effects". Heat is primarily associated with absorption of high frequency EMW radiation resulting from enhanced electrical conductivity of the tissue media. Thermal effects may cause disruption of cell function and development [17]. Increment of tissue temperature in an organ is related to imbalance between heat generation and heat dissipation. Heat generation depends on SAR and energy level (power density) of emitted EMW which must exceed 100mW/cm2 to have heating impact on biological tissues [16]. In contrast, heat dissipation involves three mechanisms: heat conduction to other tissues, convection through blood perfusion, and radiation to the surroundings. Generally, the two most vulnerable organs to thermal effects are the eyes and testes because of limited capacity of heat dissipation. However, the power density of the cell phone EMW and SAR is so low that the increment of body tissue temperature is negligible at the current level of frequency and energy of EMW in modern cell phones [16].

Non-Thermal Effects The vast majority of the sustained cell phone EMW related biological consequences can be explained by "Non thermal effects". These effects include all the interactions of EMW with biological tissues without production of heat or a measurable rise in temperature. Specifically, the magnetic field, rather than the electrical field, of EMW has the most harmful potential on living organism because of its ability to penetrate human bodies while electrical field has poor human skin penetration ability [19]. In fact, the induced alternating currents in our bodies resulting from cell phone EMW exposure can explain the biological non thermal effects at tissue, cellular and sub-cellular levels.

3 Methodology**:**
In the analysis of the influences of mobile phone towards human head, thermal imaging camera is used to measure the local temperature at the side of the face and near ear-skull region. Thermal imaging camera is capable to accurately measure two dimensional temperature fields with high thermal, temporal and spatial resolutions. From thermal imaging technique, indicator of the total temperature exposure caused by RF radiation from mobile phones can be created. Data will be collected based on average 45 minutes phone operations. Two types of mobile phones will be used, with internal and external antenna with different serving frequencies. Images (thermal distribution) will be collected every 5 minutes.

Calculation: Calculation of SAR at 900 MHz and 1800 MHz

Table 2**:** Specific absorption rate (SAR in W/kg) due to the radiation of frequency 900 MHz

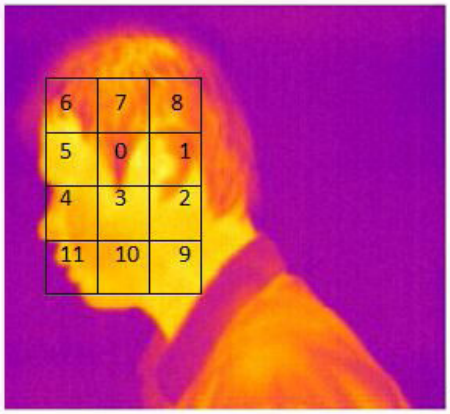
Tissues	SAR in W/kg at frequency (f)= 900 MHz at depth (0.05mm-0.25mm)				
	0.05 mm	0.10 mm	0.15 mm	0.20 mm	0.25 mm
Brain white matter	0.00001975	0.00001973	0.000019707	0.0000196821	0.0000196568
Eye sclera	0.000131126	0.000130761	0.000130397	0.000130033	0.000129671
Fat	0.000063451	0.0000634266	0.000063401	0.0000633721	0.0000633523
Skin dry	0.000088177	0.000087969	0.0000877613	0.0000875537	0.0000873466
Skin wet	0.000085551	0.000085364	0.0000851771	0.0000849904	0.0000848042
Blood	0.000168464	0.00016788	0.000167299	0.00016672	0.000166143
Blood vessel	0.000076547	0.000076406	0.000076265	0.0000761247	0.0000759845
Tooth	0.0000729519	0.0000729013	0.000072850	0.0000728	0.0000727

Table 3: Specific absorption rate (SAR in W/kg) due to the radiation of frequency 1800 MHz

Tissues	SAR in W/kg at frequency (f)= 1800 MHz at depth (0.05mm-0.25mm)				
	0.05 mm	0.10 mm	0.15 mm	0.20 mm	0.25 mm
Brain white matter	0.0000211875	0.000021581	0.0000211288	0.0000210995	0.0000210703
Eye sclera	0.0001353334	0.000134942	0.000134552	0.000134163	0.000133775
Fat	0.0000664468	0.0000664196	0.00006663924	0.0000663652	0.000066338
Skin dry	0.0000916715	0.0000914434	0.0000912169	0.0000909990	0.000090764
Skin wet	0.0000893511	0.0000891453	0.0000889394	0.000088735	0.0000885305
Blood	0.000173207	0.000172586	0.000171967	0.00017135	0.000170735
Blood vessel	0.000080011	0.0000798862	0.0000797316	0.00007957774	0.0000794234
Tooth	0.0000799321	0.00007918	0.00007931	0.0000792512	0.00007919

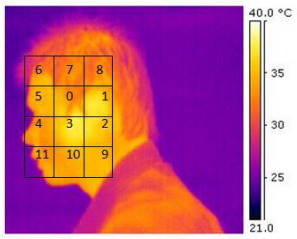
4 Result and Discussion

As mentioned earlier, the result is collected every 5 minutes using two different types of mobile phone with different frequency served. Figure 2 shows the result collected from mobile phone with internal antenna for average of 45 minutes talking time



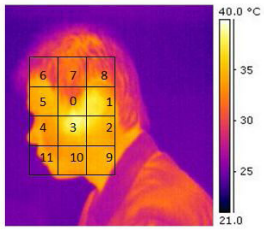
Gridline No.	Temperature ^{0}C
0	36.3
1	35.7
2	35.5
3	35.4
4	35.3
5	36.0
6	34.4
7	34.0
8	33.9
9	35.2
10	35.0
11	34.8

Figure 2: Heat Distribution on Head before the used of Mobile Phone



Gridline No.	Temperature ^{0}C
0	38.0
1	37.6
2	36.0
3	38.0
4	34.8
5	35.5
6	35.6
7	33.7
8	35.0
9	35.7
10	35.2
11	34.9

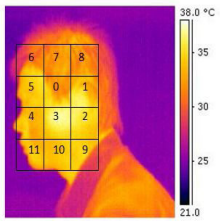
(a) GSM 900 MHz



Gridline No.	Temperature ^{0}C
0	38.8
1	37.6
2	37.2
3	39.1
4	35.2
5	35.3
6	35.2
7	33.3
8	34.7
9	35.4
10	34.7
11	34.8

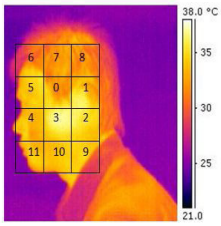
(b) GSM 1800 MHz

Figure 3: Heat Distribution using Mobile Phone (External Antenna) after 45 minutes talking time



Gridline No.	Temperature ^{0}C
0	36.0
1	36.6
2	36.5
3	37.4
4	34.6
5	35.1
6	35.5
7	33.0
8	33.3
9	34.9
10	34.9
11	34.5

(a) GSM 900 MHz



Gridline No.	Temperature ^{0}C
0	36.0
1	36.6
2	36.5
3	37.4
4	34.6
5	35.1
6	35.5
7	33.0
8	33.3
9	34.9
10	34.9
11	34.5

(b) GSM 1800 MHz

Figure 4: Heat Distribution using Mobile Phone (Built-in Antenna) after 45 minutes talking time

It can be seen from figure 2-4, are no. 3 produce more heat compare to other area especially when the user is using mobile phone with external antenna with 38.0ºC and 39.1ºC compare to 37.4ºC for mobile phone with internal (built in) antenna. This shows an increased of 2.6ºC – 3.7ºC of temperature for 45 minutes talking time. The data is summarized and show in a graph as shown in Figure 5.

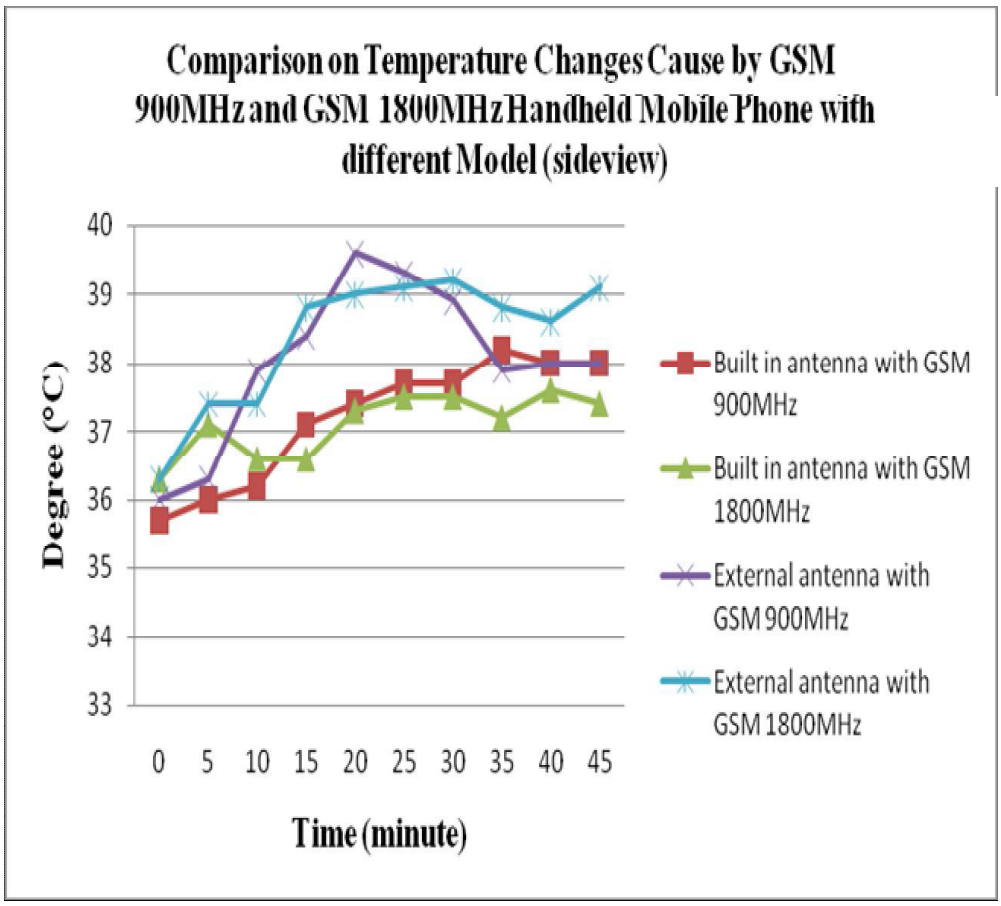


Figure 5: Temperature Changes Caused by Mobile Hand phone

From Figure 5, at 20 minutes talking time, the head temperature reach its maximum value for all types of mobile phone, with the highest temperature, 39.5ºC resulted from mobile phone with external antenna serving GSM 900 MHz, followed by mobile phone serving GSM 1800 Mhz. Both mobile phones, with built in antenna produce almost the same temperature increase to human head. As the time becomes longer, due to blood circulation of our body, the level of temperature decreased slowly. From the result, this shows that, our body has the limitation of absorbing heat transfer due to electromagnetic radiation which will take several time to low down the heat level. The absorption of heat is also different when comparing adult and children head due to the resonant frequency, the higher frequency the more radiation will be absorbed easily.

5 Conclusion

This analysis shows that the human head can absorbed the radiation from the mobile phone easily. This radiation is so-called the thermal radiation where the human head temperature increase significantly as the talking hour (period of time using the mobile phone) increased. Mobile hand phone with external antenna and serving GSM 900 shows high increase after 15 minutes operation compared to mobile phone with internal antenna and serving GSM 1800. From the above it is found that increase in temperature of human head due to the exposure of mobile phone waves increase the risk of brain cancer, more and more people should now be developing this disease. So far, the only known mechanism that mobile telephone radiation has an effect on living tissue is heating. The rise in temperature on the surface of the brain caused by radio waves is 0.3 degrees at the most. This kind of temperature rise is not known to have biological significance. The temperature of the brain normally fluctuates by about one degree, and

only after a five degree increase in temperature do cells become damaged.For future works, it is recommended to study the different of heat absorption between adult human head and children human head and using adds-on tools such as hands free, Bluetooth device and etc to reduce the effect of radiation. The time derivative of the incremental energy absorbed by or dissipated in an incremental mass contained in a volume element of a given density, is known as specific absorption rate (SAR). The specific absorption rate (SAR) by the selected tissues due to 900 MHz and 1800 MHz frequency of the radiation is calculated by eq.1 and given in tables 2 and 3 respectively. The tissues which are selected for this study are Brain white, Eye sclera, Fat, Skin dry, Skin wet, Blood, Blood vessel and Tooth.

According to some International agencies as WHO, ICNIRP, the specific absorption rate (SAR) becomes harmful after 1.6 W per kg. for a person of weight 75 kg, the safe limit of SAR is 120 W/kg. It means that, if SAR becomes greater to 120 W/kg., it may be harmful for the tissue life of the human body.

The density of bone is more than muscles. The effects on the bone tissues are lower than muscle tissue. After comparing with safe limit of SAR with the calculated data of SAR for 900 MHz & 1800 MHz, it is found that radiation of mobile phone is harmful for bone up to 0.3 mm depth when phone is kept at 1 cm distance.

6. Sugessions:

Mobile Handsets : -

1. Adoption of SAR level for mobile handsets limited to 1.6 Watt/Kg, averaged over a 6 minutes period and taken over a volume containing a mass of 1 gram of human tissue as per the FCC norms of United States.

2 . SAR value information is to be embossed and displayed in the handset.

3 . Information on SAR values for mobile handsets should be readily available to the consumer at the point of sale so that one can make sure of the SAR value of the handset while buying a cell phone.

4. Government may consider amendments in the **Indian Telegraph Act 1885 & rules notified there under** and necessary legislations if any so that only mobile handset satisfying radiation standards should be permitted for import / manufacture or sold in the country.

5. Mobile hand set manufactured and sold in India or Imported from other countries should be checked for compliance of SAR limit and no hand sets of SAR value above the prescribed standard adopted in India should be manufactured or sold in the country.

6. SAR data information of the mobile handsets should be available on the manufacturer's web site and in the manufacturer's handset's manual.

7. To bring awareness, the manufacturer's mobile handset booklet should contain the following for safe use :

a. Use a wireless hands-free system (headphone, headset) with a low power Bluetooth emitter to reduce radiation to the head.

b. When buying a cell phone, make sure it has a low SAR.

c. Either keep your calls short or send a text message (SMS) instead. This advice applies especially to children, adolescents

and pregnant women.

d. Whenever possible, use cell phone when the signal quality is good.

e . People having active medical implants should keep their cell phone at least 30 cm away from the implant.

8. The Information is made available on Government website with list of SAR values of different mobile phones.

9. To provide static continuous testing / measuring centers for online monitoring of radiation level at prominent places in
metro/cities and the data to be sent to the central server for information.

10. Apart from self certification for compliance of radiation norms on EMF exposure as is presently being done, the mobile
service providers should also measure the radiation level of certain prominent places and display it for information of the
general public. They should also have mobile unit for its measurement wherever necessary
.
11 . DOT should create a national data base with the information of all the base station, their emission levels and display on
public domain for public information.
12. Impose restrictions on installation of mobile towers near high density residential areas, schools, playgrounds and hospitals.

13 For the future expansion of telecom network in the country use low power micro cell transmitters with in-building solutions
in place of the present trend of using high power transmission over mobile towers / high rise buildings.

14. To conduct the long term scientific research related to health aspect of EMF radiation exposure and associated technologies
in India in the following areas :

- Health effect of RF exposure in children.
- Health effect of RF exposure in Foetus, mothers and elderly persons.
- Combined electromagnetic field radiation effect exposure from multiple antennas of a shared infrastructure sites

15. It is recommended for use of hands free and ear phone technologies such as blue tooth handsets and ear phone so as to
minimize the contact of head with cell phone.

16. Department of Telecom may create a document “Radio waves and safety in our daily life” indicating various Dos and
Don’ts related to mobile users clarifying various myths regarding deployment and use of radio waves and mandate each
operator to print and issue the same to their customer at the point of sale for enhanced customer awareness. This will help
in facilitating the right inputs and creating an environment where everyone can use the radio waves safely.

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