Measurement and Method in Radiofrequency Radiation Exposure Assessments.

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ABSTRACT

Radiofrequency radiation dosimetry describes how this radiation is being absorbed in the body. The basic units of measuring the radiofrequency exposure are the electric ***E*** (V/m), magnetic ***B*** (A/m) field strength, the power density ***S*** (W/m^2), and the Specific Absorption Rate (SAR) (W/kg). Many studies have made use of different types of instruments to assess the level of radiofrequency radiation exposure in an environment, and these types of equipment are either broad band meters or narrow band meters (spectrum analyzers). Different procedures or methods are used in radiofrequency radiation assessment, both in instrumentation and in measurement. From different studies, radiofrequency assessment methods are based on the study area of the studies, sampling time considered for the study, exposure distance relationship, the need for preliminary investigation and the choice of making use of a theoretical approach to the study.

(Keywords: radiofrequency, exposure, power density, spectrum analyzer, broad band)

INTRODUCTION

There is virtually no device that operates on wireless technology that does not make use of electromagnetic field (EMF) radiofrequency (RF) radiations. Mobile phone communication technology is a major breakthrough in science and it makes use of radiofrequency radiation at different frequency band and power level, depending on its application. The Global System of Mobile Communication (GSM) is the most versatile mobile communication technology in the world. This technology makes use of an arrangement of sophisticated communication systems that work together within and out of a network service.

Over the years, mobile communication has evolved from the first generation (1G) to the fourth generation (4G) mobile systems. The small size, ease of use and sophistication of GSM mobile phones are the major reasons why it has dominated the telecom market around the world. At the current state of mobile phone deployment and the annual increase in the number of people that are using them, billions people are exposed to radiation from mobile phones around the world.

In some cities, mobile phone base stations (BTSs) are found almost at every 500m interval to another, and others where there is no restriction on the location of the towers more than 30 cell towers can be seen within 1km^2 (Sivani and Sudarsanam, 2012). Since more users are emerging every day, the proliferation of mobile Base Transceiver Station (BTS) or mast is of great concern (ARPANSA, 2000). The radiation emitted from the numerous antennas mounted on the mast of the cell cite are also of great concerns to the populace, especially people who lives close to them. Therefore this paper aims at highlighting the important areas of environmental RF exposure assessment, ranging from its dosimetric quantities to methods or procedure used during assessments.

RF RADIATION EXPOSURE QUANTITY AND UNITS

Radio frequency (RF) dosimetry describes how external RF electromagnetic fields (EMF) are absorbed and distributed in different organs of the body (Ahlbom et al., 2012). The basic quantities for estimating RF energy in a medium are the electric ***E*** (V/m) and magnetic ***B*** (A/m) field strength. These quantities are mostly assessed in air and may be used to directly estimate the exposure to RF energy in a body. This does not give an accurate measure of the absorbed RF energy in the body, since it depend on the frequency of the field, and the size and orientation of the body. The power density ***S*** (W/m^2) is another important quantity in RF exposure assessment that is often used in several studies and also as the main quantity for standard limits. Both ***E*** and ***H*** are directly related to power density by the equation (ICNIRP, 1998):

$$S = EH = \frac{E^2}{377} = 377\Omega H^2 \qquad \textbf{(1)}$$

Where 377 Ω is the characteristic impedance of free space.

As far back as 1974 the concept of Specific Absorption Rate (SAR) has being used as part of RF dosimetry (Gandhi, 1974). SAR is a measure of the absorbed RF energy in the body per time and mass unit (W/kg). It is related to the electric field strength ***E*** using the equation (IEEE, 1999; ANSI, 1982),

$$SAR = \frac{\sigma \left| E_{eq} \right|^2}{\rho_{md}} \qquad \textbf{(2)}$$

Where σ the conductivity of the material, $\boldsymbol{E}_{eq}$ electric is field strength and ρ_{md} is the mass density of the body.

The SAR measurements are averaged either over the whole body or over a small volume of tissue, typically between 1 and 10 g of tissue (Sivani and Sudarsanam, 2012). Data on radiofrequency absorption in the body were put together by Durney et al. in 1986 (Durney et al., 1986). This development has paved way for the current advancement in both experimental and numerical RF dosimetry.

RF RADIATION EXPOSURE MEASUREMENT AND INSTRUMENTATION

The measurements of radiofrequency (RF) radiation exposure are generally done by making use of a broadband meter or by a frequency selective meter also referred to as the spectrum analyzer. Broad band meters are used to estimate the total contribution of all RF sources within a designated frequency band and this is often used in compliance assessment where the dominating RF source is known (Goiceanu and Dănulescu, 2006). A frequency selective measurement provides a single frequency radiation exposure characteristic, which is important when an RF source is needed to be identified.

There several types of broad band meters and spectrum analyzers have been used in several studies over the years. One of them is the Tektronix spectrum analyzer, Model 2712 (9kHz to 1.8GHz). This is essentially a radio receiver with the capacity to measure the power distribution of a received signal as a function of frequency (ARPANSA, 2000). The Narda spectrum analyzer SRM 3000 (100kHz to 3GHz) and SRM 3006 (9kHz to 6GHz) are portable and can present measured RF field magnitude directly as a percentage of the Federal Communications Commission (FCC) limits on exposure (maximum permissible exposures – MPEs). The accompanying probe/antenna is capable of performing narrowband spectrum measurements of signals from 27 MHz to 3,000 MHz (EPRI, 2011).

The Agilent spectrum analyzer model E4408B which covers the frequency bandwidth from 9 KHz up to 26.5GHz is also a very sophisticated instrument and was used by Perez-Vega et al in 2008 in a study (Pérez-vega et al., 2008). Other Agilent spectrum analyzer models like model E4407B and the ESA-E series have been used in some other studies. These spectrum analyzers have an inbuilt software program that controls the operation of the analyzer and records all relevant data (Okonigene and Yesufu, 2009); this is also a common feature in many other brands spectrum analyzers. The Advantest R3131 spectrum analyzer by Rohde & Schwarz is also another sophisticated instrument that has been used for RF spectrum analysis (Haumann et al., 2002).

Most of them are equipped with calibrated antennas with different frequency range. These antennas which are either directional or isotropic are placed at different heights to the ground level during measurement. The height of the antennas to the ground level can range between 1.4m to 2.0m as seen in some studies (Karunarathna and Dayawana, 2005; Shurdi et al., 2010; Ismail et al., 2010; Industry-Canada, 2008). Also measurements can be made in decibels (dB) or (dBm) and could be converted to equivalent electric field strength (V/m).

There are different types of broad band meters, but there functionality is basically the same. All of them can measure the entire signal within a range of frequency band. Although few have the function that can be used to take measurements within a selected narrow frequency band, but they will not be able to identify each frequency within this band. The radiofrequency field strength meter ALRF05 by Toms Gadgets is an example of a broad band meter with narrow band functionality. The bandwidth of the radiofrequency field meter can be set to "narrow" to allow a high pass function so that only high frequency radiations such as those emanating from cell towers can be measured (Enyinna and Avwir, 2010).

Other field strength measuring meters used in some studies include EMR-300 by Wandel & Golterman with a frequency range of 100 KHz to 3GHz. It has a three components field probe to measure the electrical field strength and can display the field strength range of 1 to 600V/m (Shurdi et al., 2010). The ALRF 05 Field Strength meter manufactured by Toms gadget (Asiegbu and Ogunlaja, 2010) and The RF Meter NBM-550 with isotropic ***E***-Field probe (100 kHz – 3 GHz) (Baltrenas and Buckus, 2011) are also broad band meters. These instruments can record and store instantaneous, maximum and mean values of electric and magnetic field values.

With the current advancement in RF assessment and dosimetry, other instruments have been developed. These include the personal dosimeters and the software/hardware modified phones power measurement tool. The personal dosimeter EME SPY 120 (Satimo, France) which can be used to estimate the dose, time pattern, and frequencies of exposure from all major RF sources exposed to each individual has been used in some studies (Viel et al., 2009; Frei et al., 2010). Also known is the ESM 140 (Maschek Germany) personal RF dosimeter. This meter on the other hand cannot measure FM and TV frequencies, and it presents a limited selectivity to differentiate between the frequency bands like the EME SPY 120 (Viel et al., 2009).

The EME SPY 120 can record the electric field strength present in 12 different frequency bands at regular intervals, with a 0.05 V/m lower detection threshold and a 5 V/m upper recording threshold (Viel et al., 2009; Frei et al., 2010). Software modified phones like those developed by Motorola Labs and Sony Ericson were used in some studies (Shoewu and Adedipe, 2010; Morrissey, 2007). The Motorola time port P7379 GSM mobile phones, was used to capture time and date-stamped power control settings every 2.5 s for a time interval up to 3 hours in a study by Morrissey in 2007 (Morrissey, 2007). The data obtained from these phones can be used to study the variation of RF power density with distance and the propagation path loss in an environment.

RF RADIATION EXPOSURE ASSESSMENTS AND METHODS

As far back as 1974 (Gandhi, 1974), efforts have been made to evaluate the effect of RF radiation to man. Many studies that have cut across man, animal and cellular response to RF radiation have been carried out over time (Hardell et al., 2001; Hocking et al., 1996; Otitoloju et al., 2010; Salford et al., 2008), some of which has been a very useful tool in the development of limit and standard to prevent possible health effect of RF radiation exposure (ANSI, 1982; IEEE, 1999; ICNIRP, 1998). Currently, the interaction of RF radiation is still known to produce thermal effect at high power densities but its mechanism of interaction in terms of non-thermal biological effect is not yet understood.

The primary goal of most studies is to estimate the worst case scenario of exposure in an environment, or to study the spread and effect of exposure in that environment. Some studies during the process of collecting and analyzing their data make use of many procedures or methods to obtain good results. Different procedures or methods can be used to assess RF radiation in an environment, both in instrumentation and in measurement. These procedures can be related to some basic factors that are considered during field measurements.

Type of Study Area

Most study areas are either classified as urban or rural area and may sometimes be divided into sub-areas depending on the study interest. In an urban areas or a relatively congested area, many spot measurements are made to account for the radiation from many base station that may be present there. Spectral measurements are mostly considered in this situation due to the fact that several radiofrequency (RF) sources are needed to be identified. These measurements take a lot of time and can be very costly. Therefore suitable procedures are developed to reduce cost and time and at the same time achieve a very good result.

One of such procedures is to first stratify and select the locations that might be of high significance to the study. This procedure was used in the assessment of RF radiation from GSM base stations in Australia (ARPANSA, 2000). This is quite a large area where measurements were performed at fourteen different locations in the country from two localities chosen from each state. These locations were chosen by local governments, who were asked to nominate two mobile telephone base stations sites in major population centers that were of concern to local communities.

In both cities and rural areas, spectral measurement can be taken in spots where high level of broad band RF exposure can be found. Since buildings, trees and other solid objects may significantly absorb, reflect or scatter the RF signals, measurements can be made at spots that maintained a direct line-of-sight with the antenna of the RF source at an height that may vary from 1.5 to 1.7 meters above ground level in open areas in the near vicinity of the GSM base station of interest (ARPANSA, 2000). These procedures ensure that irrelevant measurements are avoided and only data of the worst case scenarios are captured.

Perez-Vega et al. in 2008 carried out measurements along streets, covering most of the urban area of Santander Spain using a broad band instrument in order to register the total radiation levels contributed by all radio communication systems in the area. In this case, a car was used, running at low speed, and samples were registered by means of a portable computer and in-house PC control software (Pérez-Vega et al., 2008). His method was based on sampling the RF exposure along the streets, since it is a good representation of a space where people often occupy in an ideal city.

A study was carried out in San Francisco Bay (Kelsh et al., 2010) where the driving routes Base-station density maps of the city were provided by the two largest local networks in that area. From these base station density maps, three routes were designed to represent a dense urban environment, a suburban environment, and a rural environment corresponding with decreasing base-station density. Power control and RF output power data were collected using both software and hardware modified phones while a van is driving over the pre-established routes and also from some stationary locations.

Some studies were driven by the population of base stations or the number people using mobile phone device in specific areas. For example, out of the 23 local government areas of the rivers state Nigeria, two were selected for a study because of the presence of more GSM base stations that are installed in the areas and a greater percentage of people using handsets are resident there (Biebuma and Esekhaigbe, 2011). Some other studies have considered areas where mobile base stations are sited within 20m from residential buildings, school premises, offices, public arenas (Okonigene and Yesufu, 2009).

The Need for a Preliminary Study or Assessment

In areas where a radiofrequency (RF) exposure assessment has not been carried out, or areas where the estimate of the total or peak RF exposure is of main interest, only broad band measurements are often employed. These kinds of studies are mostly carried out in small urban or rural communities.

For example, Enyinna and Avwir in 2010 carried out a study in two local communities in Nigeria because the characterization of the radiofrequency power density and its impact on the inhabitants of these two communities are lacking (Enyinna and Avwir, 2010). In this study only few points where maximum exposures are obtained in the area are of interest. The maximum power densities close to the foot of the base stations to a radius of about 100m at 10m interval were obtained using a broad band RF meter.

In a similar study, clues to the health impact of radio frequency exposure to the general public in Aba, a city in south east Nigeria were assessed. This study was a preliminary study where measurements of RF radiation exposure level from mobile telephone base station antennas were carried out using a broad band meter (Asiegbu and Ogunlaja, 2010). In Northern Spain, a study was carried out at the request of city authorities to verify previous findings. Preliminarily, measurements were carried out of in the vicinity of the transmitting antennas and in the neighborhood of 20 mobile telephony base stations with a broad band meter before taking other measurements through the entire city (Pérez-vega et al., 2008).

Preliminary broad band measurements can be made to verify the presence of high power density due to a known RF radiation source, before actual spectral measurements are taken in an area. An example is the study carried out by Ismail et al. in 2010, where a portable broadband electric field strength meter was used to determine the area that gives the highest exposure level within the area of interest (Ismail et al., 2010). Reverse was the case in a study in Canada, where preliminary assessments were made with a spectrum analyzer to verify the dominance of FM broadcast signals in this environment before broad band measurements were made (Industry-Canada, 2008).

Study Sampling Time or Period

The time spent in the sampling of radiofrequency (RF) radiation exposure at a point may vary for different studies. A study may be designed to capture data that represent the worst case scenario in an area or the average value of exposure that can occur over a period of time. The concept of exposure time was developed as a result of the thermal effect of RF radiation in tissues. When living tissues are exposed to RF radiation there is a constant increase in its temperature over time, approximately 6 minutes (thermal time constant), where 67% of the steady state temperature increase occurs (Health Canada, 2009). This concept is mainly adopted for safety guidelines and limit by international organizations and scientific bodies, and are designated within certain frequency range usually between 100kHz to more than 30GHz (ICNIRP, 1998, FCC, 1997, Health Canada, 2009).

Most studies where RF spectral analyses were made, time averages were based on 6 to 30 minutes averaged time exposure measurements recommended by some international standards (Miclaus and Bechet, 2007; Shurdi et al., 2010; Panagopoulos, 2011). Few other studies employ data logging method, where measurements were made for a period up to 24 hours (ARPANSA, 2000) or day in epidemiological studies where personal RF dosimeters were used (Frei et al., 2009) and where daily continuous public exposure due to various RF sources were assessed (Mahfouz et al., 2011).

Exposure and Distance/Height Relationship

BTS antennas are usually placed at a certain height on the mast and are at a distance to areas where RF signals are intended to cover. The near field of an antenna is studied to prevent occupational hazard, while the far field is considered for assessing public exposure. For example the IEEE Standard C95.3-2002 (IEEE, 2002) recommends a minimum measurement distance of 20cm to minimize near field coupling and field gradient effects that occur in this region. These measurements are usually taken with broadband field probes. In some epidemiological studies, reports of some health symptoms were made by people living at different distances to Radio and GSM mast at different level of RF exposure (Wolf and Wolf, 2004; Hutter et al., 2006; Viel et al., 2009; Akintonwa et al., 2009).

Most studies take measurement at a distance at which the main beam of the RF radiation from the antenna falls to the ground level (maximally exposed areas). Distances are also considered in indoor measurements. A study by Baltrenas and Buckus in 2011 were performed indoors at distances of 0.5m from the closest window in the first, second, third and fourth floors and at distances of 0.5m from the closest wall in the ground floor because there were no windows there (Baltrenas and Buckus, 2011).

In Colville USA, measurements of RF radiation from 88,296 smart meters were made of at 0.3m to 15m in front of each smart meter using the spectral analysis (EPRI, 2011). Also some studies is considers exposure measurement at a particular interval of distance from the mobile phone base station to a distance that range from 100m to 1km (Haumann et al., 2002; Asiegbu and Ogunlaja, 2010; Mousa, 2011).

The Option of Using a Theoretical Estimation

Theoretical estimations of radiofrequency (RF) exposure provides a less stressful way of assessing the level of power density in far field region of a base station, but since RF radiation varies significantly from point to point due to absorption, reflection and local amplification from buildings and vegetation in an area, its result may vary significantly from the actual power density (Saeid and Ahmed, 2011; EPRI, 2011).

Theoretical approach to RF safety is widely in used especially in the assessment of RF radiation exposure from mobile devices (Sallomi, 2012, Luan et al., 2010) and from base station antennas (Kamo et al., 2011; Saeid and Ahmed, 2011). Safety distance analysis can be carried out with computer simulation using mathematical models and technical data of the antenna used in the transmission of RF signals in an environment (Ustuner, 2011; Singh, 2012).

Theoretical evaluation of the electromagnetic field produced by radio base stations in the city of Monselice northern part of Italy was done by using technical data of the antennas, the shape of the ground, the position and heights of all the buildings in the area (Giliberti et al., 2009). In Basel Switzerland, a study involving theoretical predictions was carried out using the exposure data of 166 human volunteers (Frei et al., 2009). In this study, an exposure prediction model was developed using personal exposure measurements, a questionnaire on potentially exposure relevant characteristics and behaviors and a geospatial propagation model of the exposure from RF transmitters at the participants' place of residence.

RF RADIATION EXPOSURE STANDARDS AND LIMITS

After measurements and assessments radiofrequency (RF) radiation exposure has been carried out, one important practice is to compare the obtained results to safety standards or guidelines. This is done as an effort to protect RF workers and the public from harmful effects that may associated with RF radiation exposure. Different organizations like the Institute of Electrical and Electronics Engineers (IEEE) (IEEE, 1999), International Commission on Non-Ionizing Radiation Protection (ICNIRP) (ICNIRP, 1998) and the Federal Communication Commission (FCC) of the USA (FCC, 1997), have set up controlling limits for both occupational and public RF radiation exposures.

Other independent scientific and government bodies involved in time to time exposure assessments of various RF sources have also published recommended safety limits, which sometimes take into consideration both the thermal and non-thermal effects. Examples of such bodies are the Electric Power Research Institute, Inc. (EPRI) USA (EPRI, 2011), Australian Radiation Protection and Nuclear Safety Agency (ARPANSA) (ARPANSA, 2000), the Health Canada (Health-Canada, 2009), and the Swedish Council for Working Life and Social Research (FAS) (Ahlbom et al., 2012).

Recently, the International Agency for Research on Cancer (IARC) which is part of the world health organization (WHO), designated RF-EMF from cell phones as a “possible human carcinogen” Class 2B (WHO, 2011). This report has encouraged the scientific community to further carry out more studies with the aim of establishing a link between RF radiation exposures from mobile communication devices and some reported health effects.

CONCLUSION

There is no doubt that over the years, a lot of work has been done to understand how radiofrequency (RF) radiation interacts with matter. Studies that cut across both environmental health impact assessments and epidemiological surveys have made use of different instruments to assess the level of RF exposure in an environment. These types of equipment are made to either capture the total radiation energy over wide range of frequency (Broad band meters) of capture RF energy at a particular frequency (narrow band meter or spectrum analyzers).

Different procedures or methods can be used to assess environment exposure to RF radiation, both in instrumentation and in measurement procedure. These procedures may depend on the size and, type equipment available, the population and types of RF sources in an area, study time line and the cost of carrying out the assessment. The major factors that that influences the choice of the method of assessing RF radiation exposure as seen in most studies are the type of the study area, sampling time considered for the study, exposure distance relationship, the need for preliminary investigation and the choice of making use of a theoretical approach to the study.

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