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MEASUREMENT AND ANALYSIS OF RADIO FREQUENCY ENERGY AND SPECIFIC ABSORPTION RATE FROM GLOBAL SYSTEM FOR MOBILE COMMUNICATIONS IN FUNAAB, OGUN STATE, NIGERIA

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ABSTRACT

This work measured and analyzed the Radio Frequency (RF) power densities to determine the absorption rate on human body from the four available 900 MHz Global System for Mobile communication (GSM) base stations, at some selected points in the Federal University of Agriculture, Abeokuta (FUNAAB), Nigeria. Measurements were conducted using Frequency-selective spectrum analyzer (Nokia 6800 Network Drive Tester) to determine the RF Power Densities (S), Electric Field Intensities (E) and the Specific Absorption Rates (SAR), using Airtel Base station as reference sample point. Standard Units values of the measured variables were obtained using standard mathematics equations. Out of ten (10) selected sampling points the maximum RF exposure was obtained at COLENG upstairs with its the power density equal 15.2 $\mu W/m^2$ which is 3.7 x 10^{-4}% of the maximum allowable value of the maximum exposure at 900 MHz. The recorded highest electric field intensities was 75.7 x 10^{-3} V/m, which is 0.18% of that specified by the International Commission on Non-Ionizing Radiation Protection (ICNIRP) maximum public exposure levels for 900 MHz. The highest obtained SAR value was 4.2635 x 10^{-3} W/kg which is 5.329% of the maximum recommended exposure level for the head region and brain tissue at 900 MHz. The results from this study are useful sources of environmental information and database to the FUNAAB community

Key words: Electric field strength, Non-ionizing radiation, Radio frequency (RF), Power densities, Specific absorption rates.

INTRODUCTION

The Global System for Mobile Telecommunications (GSM) is one of the fastest growing and most demanding telecommunication applications and telephone subscriptions in the world today including Nigeria. Nigeria has one of the largest numbers of users of GSM equipment (mobile units) in Africa; over 50% of the total population in Nigeria depends on the GSM as the easiest means of communication (Zain, 2005). However, since the introduction of mobile telephones in Nigeria, the health implication of Radio Frequency (RF) radiation from the base stations has been a subject of continuous global debate and concern among users

(Mhaske *et al.*, 2012) including the Nigerian citizens. Reviews of the effects of electromagnetic radiation on human beings conducted in late nineties by the World Health Organisation (WHO) and the Royal Society of Canada showed that exposure to weak electromagnetic fields can disturb the production of the hormone melatonin by the pineal gland in the brain, leading to an increased risk of breast cancer, Parkinson's disease and Alzheimer's syndromes (Lai, 1997). However, none of these claims are yet to be provided with evidence.

In this research work the measurement and analysis of Radio Frequency (RF) Radiation from the available four GSM operators base stations located at Federal University of Abeokuta, Nigeria shall be conducted. They are Mobile Telecommunications Network (MTN), Airtel Nigeria Limited, Globalcom Nigeria Limited, and Etisalat Nigeria Limited. The field study would be a physical measurement, evaluation of Radio frequency (RF) exposure assessment from GSM cellular base station tower radiation within the University. Using Federal Communications Commission (FCC) and International Commission on Non-Ionizing Radiation Protection (ICNIRP) as regulatory limits to determine RF power density, S, electric field strength, E and specific absorption rate (SAR) at various colleges and buildings through measurements. Measurements were conducted at different distances and geographical coordinates of the ten selected locations in FUNAAB using frequency-selective spectrum analyzer.

RADIO FREQUENCY (RF) RADIATION

An RF electromagnetic wave has both an electric and a magnetic component; electric field strength in volt per metre (V/m) and magnetic field strength in ampere per metre (A/m) and both are orthogonal to each other. It is often convenient to express the intensity of the RF energy at a given location in terms of the units specified to each component. Another commonly used parameter for characterizing the total electromagnetic field is power density. Power density is the most appropriately used term when the point of measurement is far enough away from an antenna to be located in the "far-field" zone of the antenna (Antti and Arto, 2003; Ogunmola, 2006). Power density is simply defined as power per unit area. It is commonly expressed in terms of watts per square meter (W/m^2), milliwatts per square centimeter (mW/cm^2), or microwatts per square centimeter ($\mu W/cm^2$). With respect to frequencies in the microwave range, power density is usually used to express intensity of the exposure (Antti and Arto, 2003).

The Specific Absorption Rate (SAR) rate is the rate at which RF energy is absorbed in a body. It is usually expressed in units of watts per kilogram (W/kg) or milliwatts per gram (mW/g). Its measurement is very complex, though based on thermal effects only. This is based on the concept that radio frequency energy, in milliwatts, is absorbed within grams of biological tissues. In the case of exposure of the whole body, a standing ungrounded human adult absorbs RF energy at its maximum when the frequency of the RF radiation is in the range of about 70MHz. Because of the so-called human body resonance phenomenon and consideration for children and grounded adults, RF safety standards are generally most restrictive in the frequency range between 30 to 300MHz. For exposure of parts of the body to hand-held mobile phones, partial-body SAR limits are used when considering the safety standards to control absorption of RF energy (Guy and Chow, 1996).

Radio Frequency (RF) Energy

The most important use of Radio Frequency (RF) energy is to provide telecommunications and high-speed data transmission services. Radio and television broadcasting, cellular telephones, personal communications services (PCS) such as bluetooth devices, pagers, cordless telephones, radio communications for police and fire departments, including speed radar and tracking radar, amateur radio, microwave point-to-point links and satellite communications are just few of the many telecommunications applications of RF.

Ionising and Non-IonisinRadiation

Ionization can be defined simply as a process by which electrons are stripped from atoms and molecules to form ions which may be positively or negatively charged with respect to its neutral resting state (Antti and Arto, 2003). The ionization process requires interaction with high levels of electromagnetic energy. Those types of electromagnetic radiation which produce energy sufficient to ionize biological material include X-rays and Gamma radiations.

Non-Ionizing radiation (NIR) refers to radiate energy that, instead of producing charged ions, has sufficient energy only for excitation. Nevertheless, it is known to cause biological effects. The NIR spectrum is divided into two main regions, optical radiation and electromagnetic fields. The optical region can be further sub-divided into ultraviolet, visible, and infra-red subregions. Hence RF radiations are non-ionizing.

Radiation Effects of Radio Frequency (RF) around GSM Base Stations

Many physicists argue that there is no plausible mechanism by which low levels of non-ionising radiation could affect living tissue, as magnetic fields are thought to be harmless, and electric fields flowing around, rather than through the human body. Epidemiologists however, point to the dozens of studies that have found an increased risk of cancer and cell mutations among people who are routinely exposed to pulsed radio frequency (RF) radiation (Kelly, 2005).

Shalangwa (2010) among others (Line *et al.,* 2000; Haumann *et al.,* 2003 and Thomas *et al.*2007), performed RF energy measurements due to the GSM 1800 MHz base stations of MTN, GLO and Zain/Airtel located at Mubi North, Adamawa State. For each of these masts, the measurements were taken at 10 minutes intervals for an hour using a frequency-selective spectrum analyzer at 100 metres and 200 metres away from the antenna towers at the back and at both sides of the masts. The measurements were taken at ground level and the average amounts of radiation measured in this study were 1.87 μSv/h for GLO, 2.26 μSv/h for MTN, and 1.48 μSv/h for Zain/Airtel (Shalangwa, 2010).

Biological effects can result from exposure to RF energy. Biological effects that result from heating of tissue by RF energy are often referred to as "thermal" effects. It has been known for many years that exposure to very high levels of RF radiation can be harmful due to the ability of radio frequency (RF) energy to heat biological tissue rapidly (WHO, 2011).

THEORETICAL ANALYSIS

A radio frequency (RF) electromagnetic wave has both an electric and a magnetic component (electric field, E and magnetic field, H), and it is often convenient to express the intensity of the RF environment at a given location in terms of these units specific to each component

The quantity used in measuring the rate at which RF energy is actually absorbed in a body is called the Specific Absorption Rate or SAR (Mhaske *et al.*, 2012; Ogunsola, 2006; Isabona & Ojuh, 2015; Ozovehe et al., 2015)).

Theoretically, power density of an electromagnetic plane wave is obtained from the Poynting Theorem, and it is given as (John, 2005):

$$S = \frac{1}{2}.\,\mathrm{Re}(E \times H) \quad \text{(W/kg)}$$

$$S = \frac{|E_{rms}|^2}{Z_o} \quad \text{(W/kg)}$$

$$S = Z_o\,.|H_{rms}|^2 \quad \text{(W/kg)} \qquad (1)$$

where E is the electric field intensity in (V/m)

H is the magnetic field intensity (A/m)

Z_0 is the characteristic impedance of free space equal to 377 Ohms

In the far field region of an electromagnetic wave, transmitted power density is given by (Pozar, 2007):

$$S_t = \frac{P_t G}{4\pi R^2} \text{ W/m}^2 \qquad (2)$$

where P_t is the power radiated by the antenna in watts (W)

G is the antenna gain with no units,

R is the effective distance from the antenna to the receiver in metres (m)

In some cases, measured power is taken in dBm, where:

$$\mathrm{dBm} = 10\log_{10}\mathrm{P} \qquad (3)$$

and P is the power radiated by the antenna in milliwatts (mW)

The maximum effective aperture area A_e of an antenna is given by equation (4) as:

$$A_e = \frac{D\lambda^2}{4\pi} \qquad (4)$$

where λ is operating wavelength of the antenna

D is directivity

The receiving antenna used (i.e Nokia 6630 Network Drive Test Equipment) specified an efficiency of 95%. At the GSM operating frequency of 900 MHZ, this efficiency corresponds to an effective aperture A_e of 82.64cm^2. Based on this, the effective area was then used in evaluating the power densities S, electric field strength E and SAR for the selected locations in addition to the applied standards mathematically expressions.

Specific Absorption Rate (SAR)

Specific Absorption Rate (SAR) is a measurement of the heat absorbed by tissue. SAR can be defined as the time rate of change of energy transferred to particles in an infinitesimal volume at that point, divided by the mass of the infinitesimal volume (Guy and Chow, 1996; Iortile & Agba, 2014). Usually, absorption rate is referred to the rate of energy absorbed by the object Isabona & Ojuh, 2015). However, local SAR has been estimated at a point on the brain as the absorber and not the whole human body for the purpose of this research work. It is related to the internal electric field by equation 5 as:

$$SAR = \frac{S}{\rho_{md}} \quad W/kg$$

$$SAR = \frac{\sigma|E|^2}{\rho_{md}} \quad W/kg \qquad (5)$$

where S is the absorbed power density in watts per square metre (W/m^2)
σ is the conductivity of brain tissue in per Ohms per metre ($\Omega^{-1}m^{-1}$)
ρ_{md} is the mass density of the human brain in kilograms per square metre (kg/m^2)

For a given transmitting frequency, σ and ρ_{md} are obtained using the standard values in Table 1.

Table 1: Human brain tissue dielectric parameters

Frequency (MHz)	Conductivity (σ) (Ω-1m-1)	Mass density (ρmd) (Kg/m3)
900	0.7665	1030
1800	1.1531	1030
2100	1.3102	1030

The specific allowable absorption rate SAR value over the body at any 6 minute period is 0.08W/kg (ICNIRP Guidelines, 1998).

Standard Protective Guidelines for Radio Frequency Radiations

Various local and international Guidelines for the evaluation and analysis of RF waves as related to the environments are available (ICNIRP Guidelines, 1998; John, 2005). Table 2 is the ICNIRP reference levels for general public exposure to electromagnetic fields in the frequency range 10MHz to 300GHz.

Table 2: ICNIRP reference levels for general public exposure to electromagnetic fields in the frequency range 10MHz to 300GHz (ICNIRP, 1998)

Frequency Range	Electric Field Strength, E [V/m]	Magnetic Field Strength, H [A/m]	Power Density, S [W/m2]
10- 400MHz	28	0.073	2
400-2000MHz	1.375f1/2	0.0037f1/2	$\frac{f}{200}$
2-300GHz	61	0.16	10

***where *f* is the frequency of the RF carrier in Megahertz (MHz)**

Hence, for 900MHz, the maximum E is 41.25V/m and maximum S is 4.5W/m^2; for 1800MHz, the maximum E is 58.33V/m and maximum S is 9.02W/m^2.

RESULTS AND DISCUSSION

The received signal levels (RSL) from the four available GSM base stations in the FUNAAB campus were measured at ten (10) selected points as shown in Table 3, considering an operational frequencies of 900 MHz, using the frequency-selective spectrum radiation analyzer (Network Drive-test Equipment) twice a day for one month. The selective radiation metre is a hand-held selective measuring device for safety analysis of RF and microwave electromagnetic fields. It consists of a basic unit and a measurement antennae. The basic unit consists of a spectrum analyzer for 100kHz to 3GHz frequency ranges. Its triaxial antenna allows isotropic (non-directional) measurement from 75MGz to 3GHz making the instrument useful for this application.

The obtained values from the measurements were recorded in dBm which is a logarithmic ratio scale of the received powers as shown in Table 4. The signal power readings represent the six surrounding cells at of the ten locations. The readings were taken in dBm units. Then, the received power was converted to the SI unit of power in watt (W), or milliwatt (mW) by taking the antilog of dBm. The power density at the selected points on the FUNAAB campus was then calculated from the measured values of downlink radiation obtained.

The Airtel base station location was chosen as the reference point. The four base stations analyzed in this report were all located within ten metres distance of each other. Therefore, we can safely assume that the three base stations were located at approximately the same point. The choice of Airtel base station as the reference point was made for ease of calculation. Table 3 is a measured distances from the GPS coordinates. The raw data obtained from the actual measurement of the received signal level, expressed in dBm is shown in Table 4. The negative logarithmic values indicate a power level below 1mW. The calculated electric field strength, power density and SAR for 900 MHz operating frequency using expressions 1 to 4 and the data in Table 1 are shown in figures 1,2 and 3.

From figure 2, the highest power density recorded which occurred at the COLENG 1st Floor. This was 15.200 $\mu W/m^2$ and is 3.7 10^{-4} % of the maximum exposure level at transmitting frequency of 900 MHz. The highest electric field intensity *E* recorded was 75.7 x 10^{-3}V/m which is 0.18% of ICNIRP maximum exposure levels at 900 MHz for public exposure. Similarly from figure 3, the highest level of SAR obtained was 4.2635 x 10^{-3} W/kg which is 5.329% of the maximum recommended exposure level for the head region and brain tissue at 900 MHz. The analysis revealed that the highest power density, electric field and SAR at 900 MHz were produced by MTN, and the location was at COLENG 1st Floor. However these values are below the maximum allowable safe values.

Table 3: GPS Coordinates of Various Colleges and Buildings, obtained from Google Earth

SAMPLE POINT LOCATIONS		GPS COORDINATES	HORIZONTAL DISTANCE (m)	DIRECT WAVE DISTANCE (m)
NAME	DESIGTION			
AIRTEL BASE STATION (Reference Point)	Ref.	Latitude: 07.23060 Longitude: 03.43560 Elevation : 159 m	0	0
COLENG	A	Latitude: 07.23004 Longitude: 03.43472 Elevation: 145m	118.10	136.65
NIMBE ADEDIPE LIBRARY	B	Latitude 07.23075 Longitude: 03.43680 Elevation : 155m	130.10	144.89
SENATE BUILDING (GROUND FLOOR)	C	Latitude: 07.23098 Longitude: 03.43779 Elevation: 153m	242.00	258.74
MANCOT BUS STOP	D	Latitude: 07.22956 Longitude: 03.43970 Elevation: 145m	463.60	469.26
COLANIM	E	Latitude: 07.23209 Longitude: 03.43701 Elevation: 158m	225.00	233.12
COLVET	F	Latitude: 07.23306 Longitude: 03.43738 Elevation: 155m	334.80	340.84
COLNAS	G	Latitude: 07.22921 Longitude: 03.43677 Elevation: 153m	199.30	209.85
ANENIH LECTURE HALL	H	Latitude: 07.22879 Longitude: 03.43531 Elevation: 150m	204.30	215.44
FEMALE HOSTEL	I	Latitude: 07. 23212 Longitude: 03.43297 Elevation : 140m	338.60	347.17
MALE HOSTEL	J	Latitude: 07.23347 Longitude: 03.43347 Elevation: 142m	398.30	405.31

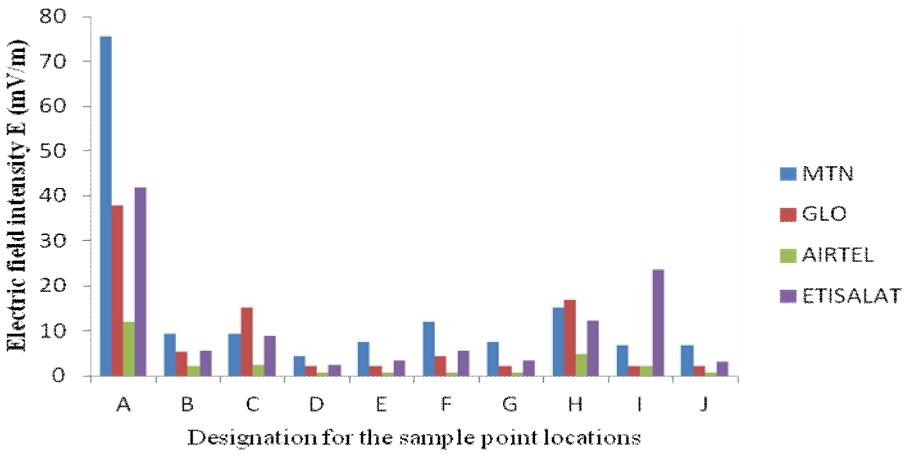

Figure 1: Observed electric field strength (E) at sample locations

Table 4: Received Power Readings in dBm for GSM 900MHz

SN	DESIGNATION	RECEIVE SIGNAL LEVEL 900MHz (dBm)			
		MTN	GLO	AIRTEL	ETISALAT
1	A	-39, -56, -56, -64, -70, -91	-45, -52, -55, -78, -88, -89	-55, -65, -78, -88, -88, -89	46, -58, -63, -76, -82, -90
2	B	-57, -71, -74, -80, -83, -83	-62, -78, -81, -86, -90, -90	-82, -92, -98, -101, -107, -104	-67, -80, -84, -89, -93, -92
3	C	-57, -66, -68, -71, -81, -86, -89	-53, -67, -84, -85, -95, -100	-69, -89, -90, -93, -96, -98,	--59, -74, -81, -83, -91, -94
4	D	-64, -83, -86, -89, -98, -100, -104,	-84, -93, -98, -109, --111, -111	-92, -92, -98, -101, -107, -104,	- 80, -89, -94, - 100, -105
5	E	-59, -66, -88, -92, -94, -101	-74, -97, -104, -106, -111, -111	-95, -101, -101, -105, -107	-76, -88, -98, -101, -104
6	F	-55, -64, -74, -77, -92, -92	-68, -64, -84, -90, -101, -103	-92, -99, -101, -103, -104, -108	-72, -76, -86, -90, -99, -101
7	G	-59, -69, -74, -76, -86, -95	-75, -91, -95, -102, -105, -107	-96, -102, -105, -106, -107	78, -87, -91, -95, -99, -104
8	H	-53, -60, -82, -85, -85, -88	-52, -64, -70, -72, -86, -90	-63, -71, -78, -81, -86, -98	-45, -65, -77, -79, -86, -88
9	I	-60, -78, -82, -88, -98, -99	-80, -90, -98, -98, -99, -100	-75, -88, -90, -91, -98, -100	-60, -78, -82, -88, -98, -92
10	J	-60, -82, -87, -88, -96, -100	-82, -91, -97, -108, -111, -111	-94, -94, -98, -101, -107, -104	-78, -89, -94, -69, -104, -105-

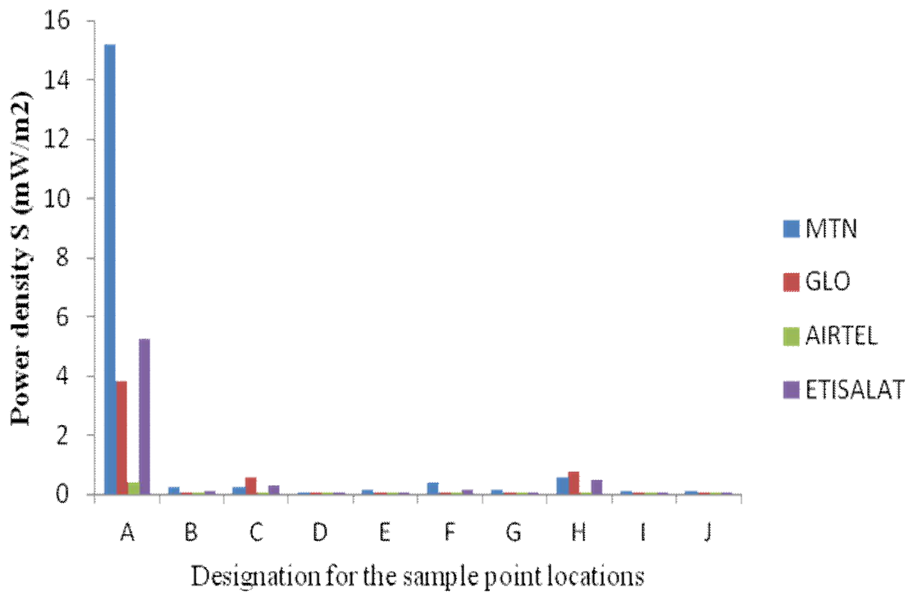

Figure 2: Observed power density (S) at sample locations

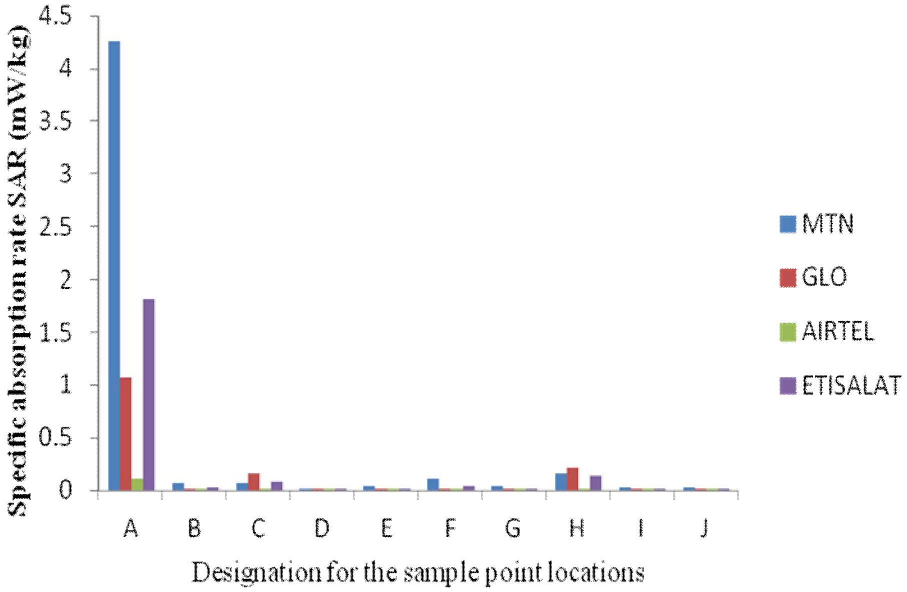

Figure 3: Observed specific absorption rate (SAR) at sample locations

CONCLUSION

It has been known for many years that exposure to very high levels of RF radiation can be harmful due to the ability of radio frequency (RF) energy to heat biological tissue rapidly. The results from this work showed that the maximum RF exposure levels obtained within FUNAAB are far below the maximum exposure levels recommended by the FCC and ICNIRP. The maximum obtained value was 15.200 μW/m^2 which is 3.7 10^{-4} % of the maximum exposure. All values of receive signal level obtained were negative in dBm, signifying that all values of the received power at all points within Federal University of Agriculture, Abeokuta are less than 1 mW. Also the maximum obtained values of Electric Field Intensity (E) and SAR were 75.7 x 10^{-3}V/m and 4.2635 x 10^{-3} W/kg, which are much lower than the reference levels set by FCC and ICNIRP. Hence, they are within the safety limits for public exposure. The results from the analysis shall reduce the fears of the community at the sight of the GSM mast. These results have also created a database of RF levels and as well as sources of environmental information for the University community.

Though the results from the analysis showed that FUNAAB environment is saved from effect RF radiation, it is recommended that this measurement is repeated whenever addition BTS station is installed in the campus.

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