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A Model for Monitoring GSM Base Station Radiation Safety in Nigeria

*Dr. Godfrey Ekata, **Dr. Ivica Kostanic
*Faculty of Computing & Applied Sciences, Baze University, Abuja, Nigeria
**Dept. of Electrical and Computer Engineering, Florida Tech. Melbourne, Florida, USA

ABSTRACT
A guideline for measuring the radio frequency (RF) emissions from the base transceiver stations deployed by Global System Mobile Communications operators in Nigeria is proposed. The guide includes the procedures for measuring the emitted RF power and for determining whether or not the emission exceeds the maximum permissible limits in Nigeria airspace.

Keywords: base station RF power emission, BTS RF power, maximum permissible exposure, non-ionizing radiation, radiation exposure, radio frequency energy emissions

I. INTRODUCTION

Wireless Global System for Mobile Communications (GSM) dominates the Nigerian telecom industry, accounting for about 98% share of the market (NCC, 2014). Four GSM operators (Airtel, Etisalat, Globacom, and MTN) control the industry in Nigeria. According to the Nigerian National Communications Commission (NCC), the number of deployed transceiver stations (BTSs) or cell sites by the four operators grew from zero in 2001 to about 44,000 in May 2014. As of May 2014, the GSM operators collectively have a subscriber base of approximately 178 million lines out of which 131 million lines were active as. This astronomical growth of GSM deployment suggests a proportionate increase in the amount of radio frequency radiation emitted into the country's air space, a trend that deserves regular monitoring through appropriate measurements of the RF power given out by the base stations. This paper provides a guide for performing the measurements in Nigeria.

II. BACKGROUND

Mobile phones and their BTS or base station counterparts are two-way radios, and produce non-ionizing radio frequency energy (Mouly & Pautet, 1992; Moulder, 2006). In general the amount of radio frequency (RF) energy emitted by a BTS is relatively low to constitute public health hazards. However, if a BTS is allowed to operate out of compliance and standards, it can emit high level of RF energy, which exposes the public and equipment to unsafe radiation and its attendant risks (ICNIRP, 2001; IEEE COMSAR, 2000). This is especially true for BTSs that are located in residential or business areas that must not radiate RF energy at the levels that are harmful to humans. In addition, a BTS emits electromagnetic compatibility (EMC) that could interfere with private and public equipment such as navigational instrument, television and radio broadcast, medical equipment and so on (ARPNSA, 2002; Industry Canada, 2011). Both the RF energy and EMC must be measured regularly to ensure human and equipment safety.

2.1 Exposure to Radio Frequency Radiation

Safety guidelines for maximum permissible exposure (MPE) of the public to the RF energy produced by GSM base stations and their antennas have been published by many nations for national and international adoption and use. According to COMAR (2000, p. 2), the "most widely accepted standards are those developed by the Institute of Electrical and Electronics Engineers and American National Standards Institute (ANSI/IEEE), the International Commission on Non-Ionizing Radiation Protection (ICNIRP), the National Council on Radiation Protection and Measurements (NCRP)", and Royal Society of Canada (RSC) (Moulder, 2000; Portland Public School, 2002).

The official guidelines of the Nigerian Communications Commission, the government agency charged with defining standards in matters relating radio, television, wired, wireless, satellite, and cable communications in Nigeria is unknown as of this publication. As a result, it is uncertain whether the National Environment Standards Regulation and Enforcement Agency (NESREA), the Nigerian enforcer of such standards, is able to order GSM operators' conformance with any or the international acceptable limits for safe exposure to RF energy, limits that must be adopted and complied with locally.

These limits are given in terms of the Specific Absorption Rate (SAR), which is a measure of the amount of radio frequency energy absorbed by the body from cellular infrastructures and their mobile phones. GSM operators worldwide must respect these limits (Moulder, 2012). Otherwise, public safety and the functioning of critical radio and communications equipment would be compromised. Table 1 shows the relationship between the RF levels required to produce known biological effects, the RF levels specified in international safety guidelines, and the RF levels found near BTSs (NCRP, 1986; IEEE, 1995; and ICNIRP, 2001).

Table 1: Standards for Base Transceiver Stations

BTS Power	Effect
10 W/m²	**Clear Hazards with reproducible effects**
1W/m²	**Unconfirmed reports of effects**
0.1W/m²	**FCC/IEEE/ICNIRP Public exposure standards**
0.57 W/m²	**UK/Australia/ICNIRP Public exposure standards**
0.1 W/m²	
0.01 W/m²	Maximum measure near a BTS
0.001 W/m²	Typical measure near a BTS
0.0001 W/m²	

Cellular infrastructure uses radio frequency Electro Magnetic (EM) waves to communicate with mobile phones. It is well understood, that an uncontrolled emission from radio equipment may cause radiation levels that are potentially harmful to humans (NCRP, 1996; Aweda et al, 2010). For that reason, in the process of manufacturing all equipment undergoes a rigorous testing for electromagnetic compatibility that ensures their safety under normal operating conditions. In many cases, however, particular installations of the cellular equipment may deviate from what was envisioned by the equipment manufactures and the levels of the radiation may be at harmful limits. To determine if that may be happening RF engineers use Electro-Magnetic Compatibility (EMC) measurements of the EM flux density in the areas surrounding the cellular infrastructure equipment. The measurements are compared against the local EMC emission limits and the cell site installation before the cell site is qualified as either safe or unsafe for human exposure.

International bodies usually determine the levels of EM flux that is considered harmful for human exposure. In many cases, national governments augment the international rules with additional requirements. The ICNIRP provides the international recommendations for the limits on the public exposure in varying electromagnetic filed. The ICNIRP standard is used in most European countries and in many other countries throughout the world (ARPANSA, 2002; Industry Canada, 2011).

2.2 Emission Concerns in Nigeria

As a sign that Nigerians are aware and apprehensive of the dangers of unsafe BTS emissions, Thisday (2012), a Nigerian national newspaper reported "growing and worrisome concerns" in Nigeria about the health effects of radio frequency emissions from mobile phones and base stations. More recently, the Nigeria's current Minister for Communication Technology, Omobola Johnson was quoted as saying "the most dangerous and important element in the communications sector is mobile phones, because of the health and other related risks they bring" (Vanguard, 2014, ¶ 6). The minister was further reported to have said that, "there were possibilities that radio waves produced by mobile phones and antennas could interfere with important electrical equipment" (¶ 10).

In the Untied States, the Maximum Permissible Exposure (MPE) for the general public for BTSs that operate in the 1800-2000 MHz range has been set to 0.12 W/m², and the MPE for BTSs operating at 900MHz set to 0.057 W/m² (ANSI/IEEE, 1999). In the United Kingdom, Australia, and New Zealand, the MPE is 0.04 W/m² for 800 - 900 MHz and 0.09 W/m² for 1800 - 2000 MHz (ICNIRP, 1998; ICNIRP, 2010), and 0.057 W/m² and 0.1 W/m² for these same frequencies.

The MPE limits for the general public and occupational standard for Nigeria are unknown at this time. This paper focuses on measuring the radio frequency exposure level in the entire country of Nigeria using the ICNIRP standard and bearing in mind the objectives and purpose outlined in the following section (2.3 of this paper).

2.3 Purpose and Significance

The monitoring model presented in this paper is designed to assist the regulatory and enforcement agencies in Nigeria to:

- Determine whether or not the radio frequency emissions from operating GSM base stations in Nigeria exceed the maximum permissible exposure limits.
- Ensure that GSM operators in Nigeria comply with international RF emission standards for public safety.
- Protect the public from the health hazards associated with RF emissions from base stations.
- Protect sensitive public and private equipment damages from EMC and RF interference.
- Assist the Nigerian environmental standards regulation and enforcement agencies to enforce compliance with RF emission standards.

III. LITERATURE REVIEW

Seminal studies have investigated GSM operations in Nigeria. The investigations range from GSM quality of service to RF emissions from BTS antennas. However, none of the studies covered the methodology for the Nigerian regulatory agency, NESREA, to monitor BTS emissions for the entire country.

From performance perspective, Ubabudu (2013) investigated the effectiveness of GSM providers' services in Nigeria and concluded that the services have helped to reduce travelling and facilitated social interactions. Ubabudu also noted that the services have been bemired by a myriad of issues that include "exorbitant tariffs, poor audio quality, call interference, non-delivery of short message (SMS), multiple billing system, poor customer care service, and high call dropout rate" (p. 74). Using the MTN GSM network as a case study, Mughele, Tune, Longe, and Boateng (2012) studied the network's congestion complaints. The authors attributed the problems to equipment vandalization, poor weather, and high-rise buildings in the line of sight of masts rather than poor RF planning and network design that some experts suspected. Adegoke and Babalola (2011) performed an evaluation of the quality of GSM services in Nigeria and concluded that consumers were unsatisfied with the level of services provided in the country. In a related study, Popoola, Megbowon, and Adeloye et al (2009) concluded that GSM services in Nigeria were unreliable. According to Oyatoye and Okafor (2011), GSM networks in Nigeria would perform at an acceptable level if the operators optimized their networks.

While the preceding studies pertain to services, there are others that focus on the safety of the RF power emitted by GSM base stations. Nwankwo, Jibrin, and Dada (2013) performed an assessment of the radiated RF power and exposure level of BTSs in the city of Lokoja in Nigeria and concluded that the intensity of the radiated power varied from BTS to BTS. The researchers also noted that the intensity of the power decreased with distance from a BTS. In their investigation of the spatial exposure to RF emission from GSM base stations in the University College Hospital environ in Ibadan, Nigeria, Ajiboye and Osiele (2013) found that RF field exposure in the area was within the safe limits prescribed by ICNIRP.

Ushie, Nwankwo, Bolaji, and Osahun (2011) found that the level of RF energy emitted by base stations in the small city of Ajaokuta, Nigeria was well below the ICNIRP safety limits. Their finding was based on the study carried on the four major GSM operators in the area. In a case study, Ahaneku and Nzeako (2012) investigated the level of RF power radiated by GSM base stations in the University of Nigeria, Nsukka. The researchers concluded that the total exposure to humans in the university environment was within the safety level recommended by ICNIRP and ANSI. Akpolile and Osalor (2014) examined the health implications of exposure to GSM antennas (masts) in selected areas of Delta State, Nigeria. The authors established that the level of exposure to GSM RF in the areas was below ICNIRP recommended limits that pose health risks. In assessing the measurement methods of RF exposure, Ayinmode and Faral (2013) argued that different methods and instrumentation are used depending on the equipment type, population size, sampling, study duration, and cost.

IV. METHODOLOGY

4.1 Model Framework

RF waves and RF fields have electrical and magnetic characteristics, and their measurements are expressed in volts per meter (V/m) and amperes per meter (A/m) respectively (OSHA, 1990; EPRI, 2011). The RF standards are expressed in plane wave power density, which is measured in milli-watts per square centimetre (mW/cm²) or in watts per square meter (W/m²). This power density or RF exposure is determined from far-field measurements of the magnetic and electrical characteristics of the radiated RF in open space.

As indicated in section 2.1, the ICNIRP standard provides two sets of exposure limits. The first set (higher tier) is referred to as the *Occupational* while the second set is referred to as the *General Population*. A summary of the limits for the occupational exposure to the EM radiation is provided in Table 2.

Table 2: Reference Values for Occupational Exposure to Time Varying EM Fields

Frequency Range (f)	Electric Field (E) (V/m)	Magnetic Field (H) (A/m)	Power Density (S) (E, H Fields) (mW/cm²)
<1 Hz	—	163×10^3	—
1 - 8 Hz	20,000	$163 \times 10^3/f^2$	—
8 - 25 Hz	20,000	$2.0 \times 10^4/f$	—
0.025 - 0.82 kHz	500/f	20/f	—
0.82 - 65 kHz	610	24.4	100; 22,445
0.065 - 1 MHz	610	1.6/f	100; $100/f^2$
1 - 10	610/f	1.6/f	$100/f^2$
10 - 400 MHz	61	0.16	1.0
400 - 2,000 MHz	$3f^{1/2}$	$0.008f^{1/2}$	f/400
2 - 300 GHz	137	0.36	5.0

Sources: STFC Safety Code No 23 (2013) & CCOHS - Canadian Centre for Occupational Health & Safety (2009).

The table provides the values of maximum exposure in various frequency bands. The exposure is expressed either in the electrical field strength, magnetic field strength or as the power density. These quantities are not independent. However, in the region that is close to the radio emitter, the nature of this dependency is not simple and the compliance with both electric field and magnetic field limits needs to be verified. The region close to the EM radiator is called *near* field region. This region extends from the radiator to the distance that can be calculated approximately as

$$D = 2L^2 / \lambda \text{ z} \qquad (1)$$

where D is the near field boundary, L is the length of the antenna and λ is the wavelength.
As an example, in the case of a 1m long cellular antenna operating in the 900MHz frequency band, the near field region extends up to

$$D = \frac{2L^2}{c/f} = \frac{2 \cdot 1^2}{3 \times 10^8 / 900 \times 10^6} = 6 \text{ m} \qquad (2)$$

In (2), c indicates the speed of light and f is the operating frequency.

As in Table 2 the summary of the exposure limits for the general public exposure to the EM radiation are provided in Table 3.

Table 3: Reference Values for General Public Exposure to Varying EM Fields

Frequency Range (f)	Electric Field (E) (V/m)	Magnetic Field (H) (A/m)	Power Density (S) (E,H Fields) (mW/cm²)
<1 Hz	—	3.2×10^4	—
1 - 8 Hz	10,000	$3.2 \times 10^4/f^2$	—
8 - 25 Hz	10,000	4000/f	—
0.025 - 0.8 kHz	250/f	4/f	—
0.8 - 3 kHz	250/f	5	—
3 -150 kHz	87	5	2.0; 995
0.15 - 1 MHz	87	0.73/f	2.0; $20/f^2$
1 - 10	$87/f^{1/2}$	0.73/f	2.0/f; $20/f^2$
10 - 400 MHz	28	0.073	0.2
400 - 2,000 MHz	$1.375f^{1/2}$	$0.0037f^{1/2}$	f/2000
2 - 300 GHz	61	0.16	1.0

Source: STFC Safety Code No 23 (2013)

The region outside of the boundary given in (1) is referred to as the *far filed* region. In the far filed region, the magnitudes of the electrical and magnetic fields are related through simple relationship given by

$$\boldsymbol{E} = \eta \boldsymbol{H} \qquad (3)$$

where $\boldsymbol{E}$ is the RMS value of the electrical filed, $\boldsymbol{H}$ is the RMS value of the magnetic filed and η is the characteristic impedance of the free space, which is 377 ohms. Additionally, the power density is related to electric and magnetic field through

$$\boldsymbol{S} = \boldsymbol{E} \times \boldsymbol{H} \qquad (4)$$

and therefore,

$$|\boldsymbol{S}| = \frac{|\boldsymbol{E}|^2}{\eta} = \eta |\boldsymbol{H}|^2 \qquad (5)$$

For a vast majority of cellular installations, the antennas are positioned far above the ground and there is no exposure to the near-filed radiation. Therefore, the measurements are usually performed in the far field of the base station antennas and the relationships in (3) to (5) hold.

4.3 Application of Model and ICNIRP Guidelines to GSM Systems in Nigeria

In Nigeria, GSM systems are deployed in two frequency bands — the 900MHz band and 1800MHz band (NCC, 2014). In the 900MHz band GSM transmission from the BTS equipment is in the between 935MHz and 960MHz, and in the 1800MHz band the BTS transmission is between 1805MHz and 1880MHz. Table 4 shows the occupational radiation limits for base stations transmitting in the 900MHz and 1800MHz bands.

Table 2: EM Radiation Limits for Occupational Radiation Exposure in 900 and 1800 MHz Bands

Frequency R ange (f)	Electric Field (E)	Magnetic Field (H)	Power Density (S) (E, H Fields)
	(V/m)	(A/m)	(mW/cm²)
935 MHz	91.73	0.24	2.34
947.5 MHz	92.34	0.25	2.37
960 MHz	92.95	0.25	2.40
1805 MHz	127.46	0.34	4.51
1842.5 MHz	128.77	0.34	4.61
1880 MHz	130.08	0.35	4.70

Organizations such as the Australian Radiation Protection And Nuclear Safety Agency (ARPANSA), IEEE, NCRP, ICNIRP, and the United Kingdom National Radiation Protection Board (NRP) have established limits for human exposure to RF fields (Adair et al, 2000). Table 5 shows the ICNIRP-recommended general public radiation limits for base stations transmitting in the 900MHz and 1800MHz bands.

Table 3: EM Radiation Limits for General Public Exposure Radiation in 900 and 1800 MHz Bands

Frequency Range (f)	Electric Field (E)	Magnetic Field (H)	Power Density (S) (E, H Fields)
	(V/m)	(A/m)	(mW/cm²)
935 MHz	**42.04**	**0.11**	**0.47**
947.5 MHz	42.32	0.11	0.47
960 MHz	42.60	0.11	0.48
1805 MHz	**58.42**	**0.16**	**0.90**
1842.5 MHz	59.02	0.16	0.92
1880 MHz	59.62	0.16	0.94

From Tables 4 and 5, it is evident that the guidelines for general public exposure are stricter than the occupational exposure. Since a majority of the cellular installations in Nigeria are outdoors in what is qualified as general public areas, the compliance testing adopts the limits provided in Table 5.

Additionally, one observes that the limits are somewhat stricter on the lower end of the band. In general practice, the cells are changing the frequency assignments with every new frequency plan. It should be assumed that at some point any given cell might be operating at the lower end of the frequency band and therefore, the lower end limits should be adopted. As results, the values in the shaded cells of Table 5 are adopted for use in this model.

4.3.1 Sample Selection

Approximately 940 base stations are recommended for testing in the 37 states (including the Federal Capital Territory) of Nigeria shown in Table 6. The 940 BTSs are distributed throughout the testing area to reflect a true deployment representation in the country. It is assumed that the suggested number of base stations represents a statistical valid sample for the four GSM operators in Nigeria. The sample will be sufficient to establish typical BTS operating conditions through out the country.

Table 6: State Distribution of BTS Testing

No.	State	BTS	No.	State	BTS
1	Abia	25	20	Kano	30
2	Adamawa	24	21	Katsina	24
3	Akwa Ib	26	22	Kebbi	22
4	Anambra	28	23	Kogi	20
5	Bauchi	27	24	Kwara	24
6	Bayelsa	26	25	Lagos	36
7	Benue	26	26	Nasarawa	25
8	Borno	26	27	Niger	25
9	Cross River	25	28	Ogun	24
10	Delta	26	29	Ondo	24
11	Eboyin	26	30	Osun	25
12	Edo	27	31	Oyo	28
13	Ekiti	26	32	Plateau	24
14	Enugu	24	33	Rivers	26
15	FCT	28	34	Sokoto	24
16	Gombe	22	35	Taraba	22
17	Imo	26	36	Yobe	24
18	Jigawa	25	37	Zamfara	22
19	Kaduna	28			
TOTAL					**940**

4.3.2 Predicted Radiation from GSM Base Stations

To determine expected values of the power density and electrical field for a typical cellular base station deployment, a simple theoretical model is adopted. Assuming that in the proximity of the base station one may apply the free space propagation model, the power density of the EM radiation is given by

$$S = \frac{\mathrm{ERP}}{4\pi \mathrm{d}^2} \quad (6)$$

Where ERP is the effective radiated power expressed in W and *d* is the distance from the cellular tower expressed in meters (FCC, 1997).

From (6) and using the relationship between power density and electrical filed in (5), one obtains

$$|\boldsymbol{E}| = \sqrt{\frac{ERP}{4\pi d^2}\eta} \quad (7)$$

To get some idea on the values from a typical GSM installation, consider the following example:

Example 1. Consider a typical cellular installation in which a cellular tower is deploying 100W ERP per

TRX and using 12 TRXs in the bases station. The total ERP radiated may be calculated as

$$ERP_{CELL} = 12 \cdot 100 = 1200 \text{ W}$$

The corresponding power density at various distances from the cell site is calculated using (6) and presented in Figure 1. As one may see, all values are below the limits given in Table 5.

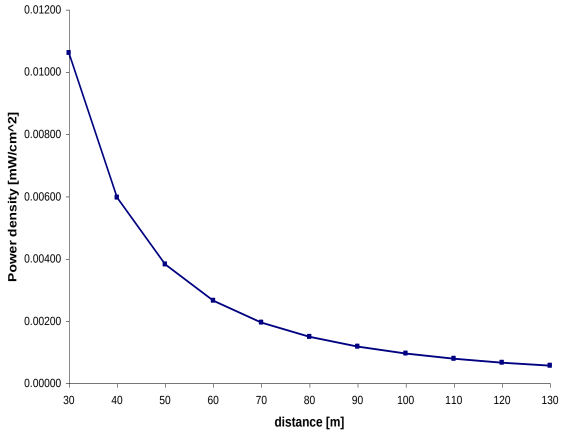

Figure 1: Power density as a function of distance for a typical GSM installation

Based on Example 1, under nominal operating conditions, one expects GSM base stations to radiate well within the prescribed limits. However, under circumstances of improper engineering and installations the radiated energy may exceed the limits. Verify if that is the case through appropriate field measurements.

4.3.3 Field Measurements of EM Radiation from GSM Base Stations

Field measurements of the EM radiation from base stations can be performed using an EMC analyzer such as the Agilent E7402A and a field meter such as EMCTD Smart Fieldmeter RFP-04. Here, the EMC analyzer is used to establish the dominant frequency range for the RF energy, while the Fieldmeter is used to establish the total power density at the measurement location. This way the level of radiation as well as the primary source of radiation can be determined. In a situation where the radiation limits are exceeded this procedure isolates the cause. Sections 4.3.3.2 and 4.3.3.3 outline the steps for performing the procedure.

4.3.3.1 Prerequisite

Performing the measurements outlined in this model requires testers who are proficient in measuring EM radiation using suitable equipment such as those mentioned in this model. It also helps for the testers to be grounded in theoretical knowledge of EMC and RF emissions and propagation. All the measurements performed are to be documented.

4.3.3.2 Using the Agilent Spectrum AnaE7402A

The Agilent E7402A can be used to determine the spectrum profile for the radiation at the measurement point. By looking at the spectral signature, the tester will be able to identify the operating frequencies of the major contributors to the power density of the electromagnetic filed. In the case when the radiation limits are high this will be used to pin point the source of the radiation.

Using the Agilent E7402A requires the test engineers to:

1. Connect the Agilent E7402A to a broadband measurement antenna
2. Measure the power spectrum density of the signals in the area. An example of one such measurement is presented in Figure 2.

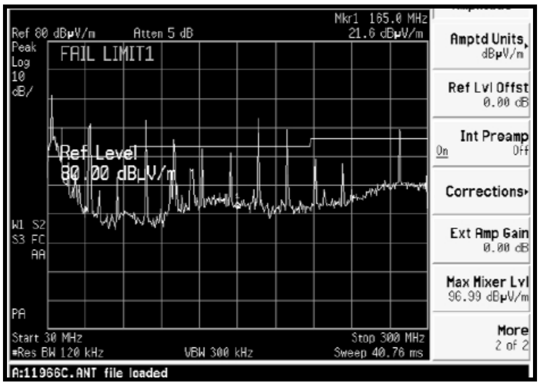

Figure 2: Example of the Agilent E7400A measurement

3. Determine and record the signals with the highest power spectral density.
4. Determine which one is the major contributor to the RF radiation, knowing the operating frequencies of the GSM operators.

4.3.3.3 Using the Smart Fieldmeter RFP-04

The RFP-04 Smart Fieldmeter can be used to measure a total level of the radio emission at the measurement location. The Fieldmeter measures the total electrical field and it is not frequency-selective. Therefore, the measured field is the aggregate field resulting from the superposition of all radiators existing in the area.

Using the EMCTD Smart Fieldmeter requires the tester to:

1. Set up the probe on a tripod.
2. Connect probe to meter, and the meter to a laptop.
3. Set up the data logger.
4. Come as close to the site and within the main beam of the antenna.
5. Mount the probe on a tripod and collect measurements for 30 minutes.
6. Obtain the mean and peak values from the measurements.

7. Calculate the power density.
8. Compare the obtained values against predictions.
9. Compare the obtained measurements against requirements of the government regulators (NCC and NERSEA).

V. CONCLUSIONS

- This work should establish procedures and regulations for overall safe operation of the cellular infrastructure in Nigeria.
- The work should transition in an on-going verification and monitoring process to ensure future compliance of all installed cellular equipment. This would encompass GSM but also CDMA and future UMTS technology.
- Based on the results of this study the NCC may be able to publish a set of guidelines for future cellular system installations. In the long run this will provide a way to avoid installation and deployment problems.

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