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A Model for Assessing base Stations for Compliance with Safety Limits for Human Exposure to Electromagnetic Fields (EMFs) in Nigeria

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***Abstract*—A model for assessing the level of EMF emission from installed base stations and confirming that the base stations comply with the prescribed exposure limits is proposed. The model includes procedures for measuring EMF levels for both controlled and uncontrolled exposures, as well as procedures for mitigating any non-conformant base stations.**

***Keywords*—EMF exposure; EMF safety limits for human exposure; exposure to electromagnetic fields; BTS emission**

I. INTRODUCTION

Base transceiver stations (BTS) or base stationsproduce non-ionizing radio frequency (RF) energythat is radiated throughitsantennas intoair. Although the amount of RF energy emitted by a base stationis relatively low to constitute health hazards to humans, a poorly installed or configured BTS could stray from the envisioned operating standards and function out of compliance, thus emitting high level of RF energy that exposes humans and equipment to unsafe radiation and its attendant hazards (Ekata, 2014, ICNIRP, 2010; IEEE, 1999; COMSAR, 2000). Besides, the BTS is an intentional emitter of electromagnetic fields (EMF),which"can exceed the safety limits depending on the operating power, power gain, frequency, orientation, and directivity of the transmitting antenna" (ITU, 2000, p. 7). Thus an installed BTS requires EMF testing to ensure compliance with the prescribed safety limits. Spurious emissions by unintentional emitters can also cause telecommunications equipment to produce EMF. However, such unintentional emittersdo not need any EMF safety assessment to assure BTS compliance with safety limits (ITU-T, 2000).

II. BACKGROUND

A BTS is that component of a wireless communications infrastructure that houses the radio that defines a cell and coordinates the radio link protocols with mobile devices such as GSM phones. A typical BTS consists of radios, amplifiers, combiners, duplexers, splitters, power supplies, an antenna system, and the software that runs the base station (Mouley and Pettit, 1995).

With the current massive deployment of GSM systems in Nigeria, it is only prudent that the country's regulatory agencies take steps similar to those of their counterparts in other countries to mitigate the potential hazards of RF radiation from installed BTS. A number of countries have developed and/or adopted national or international guidelines for checking and ensuring that emissions from installed wireless communication systems conform to EMF safety levels.

The adopted guidelines specify the Maximum Permissible Exposure (MPE) limits of EMF or RF energy that may be allowed into the environment for the general public occupational personnel. The International Commission for Non-Ionizing Radiation Protection (ICNIRP) standards and guidelines are widely used for setting national standards to restrict human bodies to EMF exposure (LEAC, 2010).

Exposure standards usually refer to electric and magnetic component or power density limits. They are individually measured when it is required by the field properties related to the field regions.Nigeria, through an act of its National Assembly, is poised to adopt the ICNIRP standard. Table 1 shows some countries and the guidelines they have adopted.

Table 1. Countries and Guidelines

Country	MPE Standard	Country	MPE Standard
Argentina	ICNIRP	Taiwan	ICNIRP
Cote d'Ivoire	ICNIRP	Singapore	FCC, ICNIRP
Brazil	ICNIRP and WHO	Pakistan	ICNIRP
Hong Kong	ICNIRP, FCC	United Kingdom	ICNIRP
Canada	ICNIRP, IEEE	D. Republic	IEC/CENELEC
Mexico	IEC/CEN ELEC	United States	FCC, IEEE

A.Exposure Limits

EMF exposure takes placewhen someone is subjected to an external electromagnetic fieldthat is separate from natural phenomena (ITU, 2000). The ICNIRP guidelinesinclude the basic restrictions that areestablishedfor EMF-induced current density in the body and the reference levels established for the strength of EMF external to the body (Stam, 2011). Because the basic restrictions are difficult to measure, the more restrictive reference level is used to determinecompliance with the basic restrictions and emission limits. ITU-T K70 (2007, p. 3) notes that, "compliance with the reference limits guarantees the compliance with basic restrictions".

1) ICNIRP Reference Levels

The ICNIRP reference levels for occupational and the general public exposuresfor the frequencies of interest are shown in Table 2.

Table 2.Applicable Reference Values for 6 Minutes Exposure to Time Varying EMF

Exposure Type	Relevant GSM Frequency Range (f)	Electric Field (E) (V/m)	Magnetic Field (H) (A/m)	Power Density (S) (E, H Fields) (mW/cm²)
Occupational	400 - 2,000 MHz	$3f^{½}$	$0.008f^{½}$	f/400
	2 - 300 GHz	137	0.36	50
Gen. Public	400 - 2,000 MHz	$1.375f^{½}$	$0.0037f^{½}$	f/2000
	2 - 300 GHz	61	0.16	10

Source: ICNIRP Guidelines

Table 3 shows the reference level by the technology used for GSM services.

Table 3. ICNIRP Reference Level by Technology

Technology	Reference Levels (V/m) Based on ICNIRP Limits for General Public
GSM 900	≈ 42 V/m
GSM 1800	≈ 59 V/m
UMTS	61 V/m
CDMA 2000	≈ 40 V/m

2) Maximum Permissible Exposure

The MPEis meant to protect humans against the adverse effects of exposure to radiofrequency (RF) EMFin the frequency range of 3 kHz to 300 GHz in which cellular communications occur (ITU, 1998). The MPElimits are thevalues of electric/magnetic field strength and power density in EMF fields above which humans are susceptible to the adverse effects of EMF.

B. Why Test or Measure EMF?

EMF measurements assist regulatory and enforcement agencies in any country to confirm base stations compliance with government rules and standards as well as to:

- Determine whether or not the radio frequency emissions from serving BTSs exceed the maximum permissible exposure limits
- Ensure that GSM operators comply with international and national RF emission standards for public safety
- Protect the public from the health hazards associated with RF emissions from BTSs
- Protect sensitive public and private equipment damages from EMC and RF interference
- Evaluate the effectiveness of RF controls
- Identify "RF Hazard" zones and other areas requiring signs and training
- Identify medical need and surveillance (Curtis, 1999)

C) When EMF Measurement Is Not Necessary

In some instances such as when the three conditions below are true, the compliance can be assessed without conducting measurements:

- When low power is transmitted by the BTS
- When the position/orientation of the transmitters/antennas is such that areas accessible to the general public is non-existent
- When simple calculation methods can be used per ITU-T K.52

III. LITERATURE REVIEW

ICNIRP (1998, 2002, 2010) developed and established guidelines for human exposure to electric and magnetic fields in the low-frequency range (9 kHz and 300 GHz) of the electromagnetic spectrum used for wireless telecommunication. The exposure limits, depicted in Table 2have become the gold standard for assessing exposure to EMF fields and have been adopted by many countries.The IEEE (1999) revised its recommendations C95.1 standards for safety levels with respect to human exposure to EMF and clarified the limits below which induced and contact currents do not have to be measured. The clarifications were similar to those provided by ICNIRP in Table 2 in terms of root mean square (RMS) electric, magnetic field strengths, plane-wave free space power densities, and contact currents in bodies exposed to such fields.

Health Canada (1996, p. 8) established a safety code relating to EMF from wireless telecommunication installations and MPE to humans, and recommended:

- The maximum levels and durations of exposure to RFfields of frequencies between 3 kHz and 300 GHz
- The maximum allowable RF contact and induced body
- General procedures for ensuring that exposure is not greater than the levels specified in the Code
- The working conditions that will lead to high standards of safety for all personnel engaged in the manufacture, operation, and maintenance of RF devices

The Australian Radiation Protection and Nuclear Safety Agency (ARPANSA) published a series of guidelines on radiation and EMF to serve the country's regulatory agencies in their functions (ARPANSA, 2002). The series includes publications on radiation protection standards, codes of practice, recommendations, and safety guide. As an example, the radiation Codes of Practice are prescriptive in style and contain "practice-specific requirements that must be satisfied to ensure an acceptable level of safety in dealings involving exposure to radiation" (ARPANSA, 2002, p. 3).

In fulfilling its role of providing advice on exposure guidelines to EMFs, the United Kingdom National Radiological Protection Board (NRPB, 2004) reviewed new scientific evidence and its previous advice of 1993 and 1999 and published its current advice for limiting exposure of people to EMFs inthe 0GHz to 300GHz frequency range. Following the review and submission by experts and other stakeholders, the NRPB recommended the adoption of the ICNRP's guidelines for limiting exposure to EMFs.

The Federal Communications Commission (FCC) of the United States (2013) reassessed its existing rules and policies guarding human exposure to EMFs and implemented changes.The amendment process elicited inputs from several related research documents, previous acts on the subject dating back to 1934, ICNIRP guidelines of 1998, IEEE Standard for Safety Levels with Respect to Human Exposure to Radio Frequency Electromagnetic Fields 3 kHz to 300 GHz of 2005, and subject matter experts. According to FCC, the reassessment helped to enhance its current recommendations for EMF exposure guidelines.

In a number of publications, the International Telecommunications Union (ITU) has provided guidelines for assessing compliance of telecommunication installations with established safety limits for human exposure to EMF produced by installations (ITU-T, 2010).The guidelines include both measurement and calculation methods for evaluating compliance. The ITU has also published various documentsfor assessing and monitoring disparate wireless installations and configurations for compliance with the MPE limits.

Kim (2009) provides two methods for measuring compliance with EMF requirements. The author noted that when performing an in situ measurement, compliance with human exposure limits is determined by the spatially averaged field value obtained within the space occupied by humans at one arbitrary position, but when performing an electromagnetic environment measurement, it is determined by the maximum value at the highest field position selected from several places" (Kim, 2009, p. 112).

Singh (2012) assessed the electromagnetic radiation of a site that provides services for GSM, 3G/UMTS, CDMA, and WiMAX technologies at Bharat Nagar, India and found that the compliance distances for each technology were different. The author determined the compliance by calculating the EIRP and EIRP threshold ($EIRP_{th}$) values at different areas in the domain of investigation comparing the values and their ratios to unity. Singh concluded that a review of the current exposure limits recommended by ICNIRP was necessary because they appeared to too generous. In confirming that base station installation in New Delhi, India comply with EMF exposure limits prescribed by the Department of Telecommunication, TEC (2012) employed the guidelines provided in ITU-T K.52 to measure the EMF limits. The ITU-T method allows telecoms providers toset up their infrastructure that enables them perform self-monitoring for EMF emission compliance, which they share with the regulatory agency for auditing.The ITU-T methodology is used in this model.

The preceding reviews highlight the need for Nigerian regulators to develop a national guideline for implementing the ICNIRP standards that is being adopted for the country. The guideline would enable the Nigerian regulator to assess any base station and audit the GMS/3G/UMTS/CDMA operators for compliance with EMF safety limits. As of this publication, evidence of a coherent national guideline and implementation procedure for assessing compliance is lacking.

IV. THEORETICAL FRAMEWORK AND DEFINITION OF TERMS

Three properties that include accessibility criteria, antenna properties, and emitter power are used to determine base stations compliance with applicable exposure limits.

A. EMF and Need for Measurements

Electromagnetic energy comprises both electric energy and magnetic energy, radiating through space and travelling at the speed of light. Electromagnetic field (EMF) is the area occupied by the energy. All base stations emit radiofrequency EMF (RF electric and magnetic waves) through their antennas, which they use to communicate with mobile phones.

The electric and magnetic characteristics of EMF are measured and expressed in volts per meter (V/m) and amperes per meter (A/m) respectively. The RF standards are measured in plane wave power density, which is expressed in watts per square meter (W/m^2). This power density is determined from far-field measurements of the magnetic and electrical characteristics of the radiated RF in open space. In the far-field region, the antenna distance is of no consequence to the EMF value.

1) Near-Field Region: The area around antenna or assessment domain boundary (ADB) is best understood from Figure 1. The ADB consists of the near-filed and far-field regions, with the near-field region broken down further into reactive near-field zone, reactive radiating near-field region, and radiating near-field (Fresnel) zone.

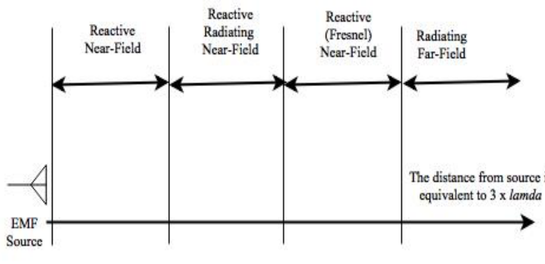


Figure 1. Fields Around EMF Source

NOTE:

- The distance is 3λ or $2D^2/\lambda$ from the source.
- The reactive near-field zone extends to a distance equivalent of one $\lambda$from the source.
- The reactive radiating near-field region is where the radiating field is becoming prominent and extends to about three wavelengths (3λ) from the source.

- The radiating near-field (Fresnel) zone is the region of the field between the far-field and near-field regions in which radiation is predominant.

In all the three zones in the near-field region, both the electric (E) and magnetic (H) components are required to be measured to determine compliance with exposure limits.

Reactive Near Field Region is the reactive near-field of an antenna with maximum extension *D* or d is defined as

$$\text{Max}\left(\lambda, D, \frac{D^2}{4\lambda}\right) \quad (1)$$

Where λ denotes the free space wavelength.

Far-Field Formula: Power density *S* in the far-field region can be evaluated using the following formula:

$$S = \frac{PG_{\theta,\varphi}}{4\pi d^2} \quad (2)$$

Where *P* is the transmitted power, $G_{\theta,\varphi}$ is the gain of the antenna in the direction (θ,φ), and *d* is the distance from the antenna to the evaluation point. The associated electric field strength, *E*, and magnetic field strength, *H*, can be evaluated as follows

$$E = \frac{\sqrt{30PG_{\theta,\varphi}}}{d^2}, \quad H = \frac{E}{\eta_0}, \quad (3)$$

Where $\eta_0 \approx 120\pi$

If the power density is evaluated in the direction of maximum antenna gain:

$$S = \frac{EIRP}{4\pi d^2} \quad (4)$$

Thus the EIRP can be derived from (4) as:

$$EIRP = S(4\pi d^2) \quad (5)$$

Antenna Gain, G (θ, φ), is the amount of power transmitted in the direction of peak radiation relative to an isotropic source. It is expressed in decibels with respect to the isotropic antenna (dBi) by the equation:

$$G(\theta, \varphi) = 4\pi \frac{dP_r/d\Omega}{P_{in}} \quad (6)$$

Where

θ, φ = The angles in a polar coordinate system

P_r = Radiated power

P_{in} = Total input power

Equivalent/Effective Isotropic Radiated Power (EIRP) is the product of the power supplied to the antenna and the maximum antenna gain relative to an isotropic antenna.

EIRP = Total output power of TRX carrier (coming out of BTS Duplexer) - Loss of waveguide + Antenna gain. For a multiple source

EIRP Threshold is denoted by $EIRP_{th}$ and represents the value that corresponds to the exposure limit for the power density.

Assessment Domain Boundary (ADB) is boundary surrounding an antenna of the equipment under test (EUT) outside of which measurements do not need to be conducted. The ADB represents the maximum possible measurement area where the source is considered to be relevant. The ADB is typically identified during measurement.

Compliance Boundary is the area outside of which the RF exposure from the EUT is below the exposure limit.

Domain of Investigation (DI): Sub-domain within the assessment domain boundary to which the general public have access.

B.EMF exposure zones

EMF exposure zones are areas or spots where people might be exposed to EMF radiated from intentional emitters. An EMF exposure zone may be a compliance zone, occupational zone, and an exceedence zone as illustrated in Figure 2.

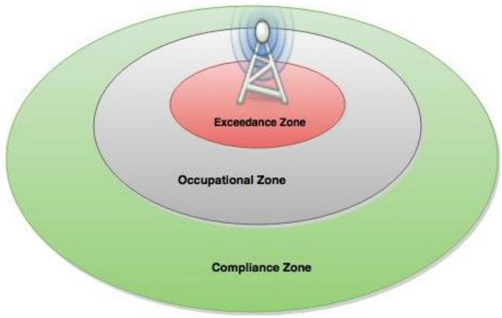


Figure 2.Exposure Zones

Compliance zone is the area with the minimum chance of exposure riskbecause the stipulated limits for controlled and uncontrolledlevelsare greater than the measured limits. In the Occupational zone, the risk exists for general public exposure but none for occupational exposure.This is because the limits are lower for controlled but higher than the uncontrolled exposure. TheExceedance zone is the area with highest risk of exposure because the EMF limits are higher than stipulated for both controlled and uncontrolled levels.

C. Base Station System Compliant

A base station is EMF compliant if the radiated EMF levels are lower than those prescribed in the applicable guidelinesor if the zones with over-the-limits EMFs are restricted to occupational and general public access. Thus an EMF source may be inherently compliant, normally compliant, or provisionally compliant.

NOTE: *Exposure limits do not imply emission limits. Instead, exposure limits pertain to spots or locations of EMF from base stations that are accessible to general public or workers who are aware of their possible exposure to the EMF spots. Therefore, compliance can be achieved by limiting access to areas or spots where the EMF limits may be exceeded.*

Inherently Compliant sources refer to EMFs that are lower than the applicable exposure limits that are close to the source.The EIRP value for the source is typically less than 2W. There are no particular precautions required for an inherently compliant source.

Normally Compliantsources or installations produce EMFscapable ofsurpassing theapplicable exposure limits. However, because of normal installation practices in wireless communications, the exceedance zone of these sources is not accessible to people unless under special conditions. An installed base station is normally compliant if the following is true:

$$\sum_i \frac{EIRP}{EIRP_{th,i}} \leq 1 \qquad (7)$$

Where $EIRP_{th,i}$ is threshold at frequency i.

Provisionally Compliant installations are those that require special measures to achieve compliance because they are neither inherently compliant nor normally compliant.

4.4 Measurement Area Selection

The DI is the part of the ADB of the BTS under test (BUT) to which the general public has access, thus requiring a general exposure assessment.

Assuming the ADB for the BUT is shaped like a box, the following simplified expression can be used to estimate the ADB.

$$D = 1.3\sqrt{\frac{EIRP}{S_{\lim}}}, \qquad (8)$$

Where *D* is the side length in meter in the main beam direction

EIRP is the EIRP (W) of the EUT

$S_{\lim}$ is the relevant power density exposure limit (W/m²).

If multiband antennas with more than one active band are been measured, the ADB may be evaluated with the following formula:

$$D = 1.3\sqrt{\sum_i \frac{EIRP_i}{S_{\lim,i}}}, \qquad (9)$$

Where

$EIRP_i$ is the EIRP of the BUT for band *i*

$S_{\lim,i}$ is the relevant power density exposure limit (W/m²) for band *i*.

4.5 Mitigation Techniques

Several techniques can be used to reduce EMF in areas that are accessible to people. Table 4 highlights some of the approaches recommended in ITU-T K.70 (ITU, 2007).

Table 4. Mitigation Methods

#	Technique	Brief Description
1	Decrease the transmitter power	This simple approach reduces radiation and EMF levels because a reduction in transmission power reduces the flux density and the E^2. The drawback is a reduction in coverage area.
2	Increase antenna height where possible	Increasing the antenna height will also increase the distance from the point of measurement, which then reduces the level of radiation.
3	Decrease in the vertical radiation pattern (VRP) down-tilt	A big down-tilt produces a big radiation levels in antenna's vicinity. However, decreasing the VRP of the main beam also limits coverage.
4	Increase in the antenna gain	Since the area covered depends very much on radiated power ERP (or EIRP), when low power transmitter is used to feed a high-gain antenna it will achieve the same EIRP as using high-power transmitter to feed a low-gain antenna. Thus using the former would better protect against radiation.
5	Changes in the HRP	Replacing a wide horizontal beam panel by one with a narrower horizontal beam which uses lower transmitter power that has no effect on the radius of coverage decrease radiation level.
6	Using multiple techniques simultaneously	This is the use of more than one of the techniques above at the same time. In addition warning signs should be posted conspicuously in areas where EMF measures exceed prescribed limits.

V. METHODOLOGY

Ideally, the GSM/CDMA/3G/UTMS/ and WiMAXservice operators set up their infrastructure to enable them perform self-monitoring of installed base stations for EMF emission compliance; they wouldshare the measurement data withgovernment regulators for EMF auditing (TEC, 2012). Nevertheless, regulatory agencies in individual countries set forth their measurement procedureor guide to certify any claim of compliance. This section contains a summary of the procedure that could be used to perform the assessment to confirm compliance.

A. Procedure

NOTE: *Sufficient understanding of RF signal and measurement skills is required for this procedure.*

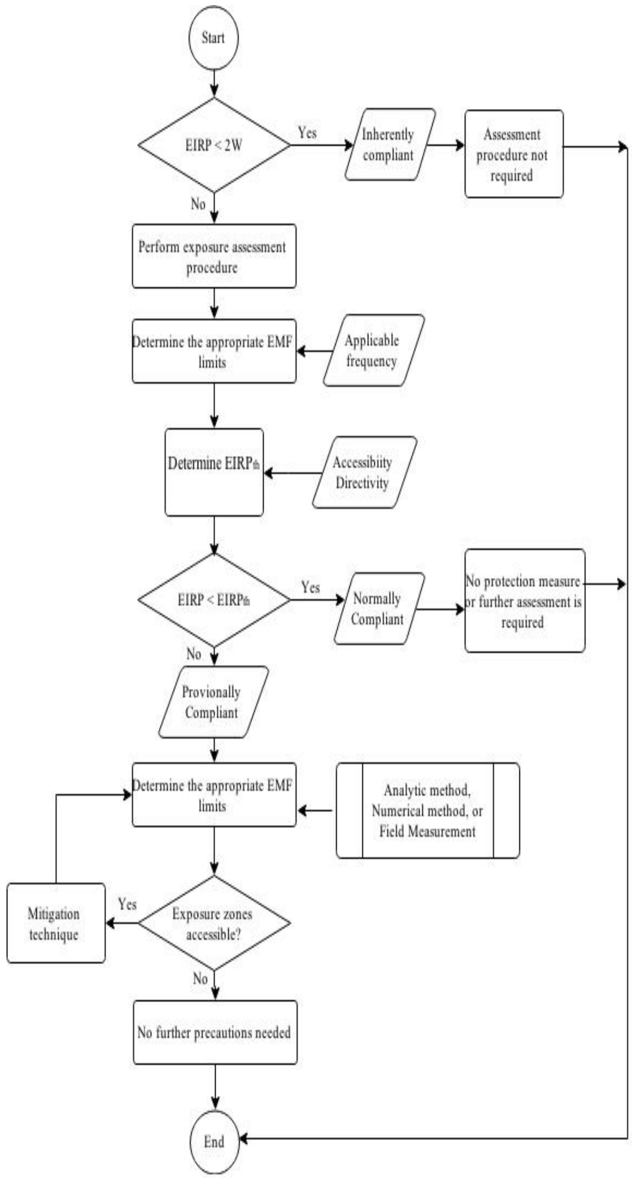
This model uses EIRP value at a given distance in a DI to determine compliance. The process, depicted in Figure 3 is a recommendation of ITU-T (ITU-T k.52, 2000).

1) *Equipment Requirement:* The following are required.

- Functional base station
- Power meter, Field Strength meter, or Spectrum analyser
- Isotropic antenna or probe to sample the field
- Laptop with EMF-Estimator software

2) Detailed Steps: ITU-T K.52 provides the following steps for assessing a BTS compliance with EMF exposure limits.

- Define the antenna characteristics.
- Define a set of accessibility conditions.
- Obtain the BTS information/characteristics.
- For step 1 and 2 above, determine the power flux density value using the equations (1), (2), and (3).
- Determine the appropriate EMF and compare to 2W.
- Preform the exposure assessment for the BTS using the information obtained in steps 1 and 3.
- Determine the appropriate EMF limits.
- Determine the threshold EIRP, which is denoted as $EIRP_{th}$ and compare with the EIRP value.
- For each location likely to experience exposure, determine the power density. The point can be referred to as O.
- Determine the maximum power density, S_{max} in the exposure region.
- The $EIRP_{th}$ is the value where S_{max} = S_{lim}, where S_{lim} is the relevant limit given by the EMF standard at the relevant frequency.
- Determine the exposure zones and compliance.
- Apply mitigation techniques where needed.
- Repeat steps 1 through 11 for other wireless protocols (3G/UMTS, CDMA, and WiMax) being studied.



Source: ITU-T K.52

Figure 3.BTS Measurement Process

VI. REPORT PRESENTATION FORMAT

The report to be presented may include certain data that were captured and used for analysis. The report may also include the calculated values for EIRP, $EIRP_{th}$,antenna distance, etc. Section 6.1and Table 5 depict the format.

6.1 Assessment Report Format

6.1.1 Technical and Legal Framework:

6.1.2 Project Scope:

6.1.3 BTS Coverage Area:

6.1.5 Project Manager:

6.1.6 Organization:

6.1.7 Lead Field Tester/Engineer:

6.1.8 Equipment and Location Identification:

Name of Station:

Address:

Type of Station:

Geographical Coordinates: Longitude:
Latitude:

Max Power Transmission per Channel:

Installation Type:

Number of Sectors:

Coverage in (Km):

Operating Band in (MHz):

6.1.9 (BTS/Antenna) Characteristics

Table 5. GSM Transmission System Characteristics

	Sector1	**Sector2**	**Sector3**
	Frequencies ___ (MHz)	*Frequencies ___(MHz)*	*Frequencies ___(MHz)*
Antenna			
Make			
Model			
Type			
Polarization			
Gain(dBi)			
Rel. Front/Back(dB)			
Height(From Ground)(m)			
AzimuthNG(degrees)			
Angle of Elevation (degrees)			
Installed Radius			
No. Max Frequency (TRX)/sector			
Pwr.trans/channel(W)			
Cable Length(m)			
Cable Type			
Total Attenuation (Equipment and Cables)(dBm)			
Power (W)			
EIRP (W)			
Specific Safety			

Distance (m)			
ICNIRP Limit, Field Strength (V/m)			
ICNIRP Ration			
Cumulative Field Strength (mV/m)			

6.1.10 Antenna Distances

Minimum distances to antennas to serve the exposure limits of the occupation and general population.

Table 6. Antenna Minimum Distances 900/1800 MHz

System ___ MHz	Controlled			Uncontrolled		
	Sector			*Sector*		
	1	2	3	1	2	3
EIRP (dBm)						
$EIRP_{th}$ (W)						
Distance (m)						

6.1.12 Observations of non-Conformance

6.1.13 Calculation of Electromagnetic Fields Produced by the Base Station

Limits for Occupational Exposure Limits for occupational exposure to the radio frequency in range between 9 kHz and 300 GHz, effective for amounts unperturbed, such as:

Table 7. Limits for Controlled and Uncontrolled Exposure Due to RF Range

Systems 1800 MHz/900MHz						
	Controlled			Uncontrolled		
Frequency Range (MHz)	E (V/m)	H (A/m)	Seq (W/m2)	E (V/m)	H (A/m)	Seq (W/m2)

CONCLUSION

The conclusive statementsshould include the minimum distances of the antennas that are maintained, with no possibilities of people getting close to the antennas in smaller radius than that calculated for General Population exposure safety.

VII. DISCUSSION

The Nigerian telecom industry has been experiencing a quantum growth during the past decade, with GSM operators accounting for about 87% of telecom services for the country of approximately 170 million people. The major operators in the country have continued to deploy their base stations through out Nigeria. However, there is little or no evidence that the operators respect or are made to respect the EMF emission guidelines to protect the health of Nigerians. It is hoped that this model will help the Nigerian regulators toinitiate a starting pointfor focusing and developing a national guideline for implementing the ICNIRP standards that is being adopted for the country.

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