

UNIVERSITY OF GHANA

**A COMPARATIVE STUDY OF RADIOFREQUENCY EMISSIONS FROM
ROOF TOP MOBILE PHONE BASE STATION ANTENNAS AND TOWER
MOBILE PHONE BASE STATION ANTENNAS LOCATED AT SOME
SELECTED CELL SITES IN ACCRA, GHANA.**

BY

GEORGE KWABLA ATAKPA

(10397235)

**THIS THESIS IS SUBMITTED TO THE UNIVERSITY OF GHANA, LEGON
IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE AWARD
OF AN MPHIL DEGREE IN RADIATION PROTECTION**

JULY, 2014

DECLARATION

This is to certify that this thesis is the result of research undertaken by George Kwabla Atakpa towards the award of the Mphil Radiation Protection in the Department of Nuclear Safety and Security, School of Nuclear and Allied Sciences, University of Ghana, under the supervision of Dr. Joseph Kwabena Amoako and Prof. John Justice Fletcher.

..... **Date**
GEORGE KWABLA ATAKPA
(Student)

..... **Date**
DR JOSEPH KWABENA AMOAKO
(Principal Supervisor)

..... **Date**
PROF. JOHN JUSTICE FLETCHER
(Co-Supervisor)

DEDICATION

I dedicate this thesis work to my lovely mum, late dad, my uncle and siblings for their prayers, love and support.

ACKNOWLEDGEMENT

Glory be to God Almighty for His love, grace, mercies and blessings He had showered unto me through all these years.

My profound appreciation to my supervisors Dr. Joseph Kwabena Amoako and Prof. John Justice Fletcher who in spite of their busy schedule patiently guided me through this research work.

I owe a debt of appreciation to the management of Radiation Protection Institute (RPI) of Ghana Atomic Energy Commission (GAEC) for making available the measurement instruments and its accessories for the research, Head of department of Nuclear Safety and Security of Graduate School of Nuclear and Allied Sciences, Management of National Communication Authority (NCA), Samuel Osei, Samuel Obeng Odame, Philip Deatanyah and all of RPI-GAEC Emmanuel Adofo, Bright Elikplim Senaya of MTN, Desmond Kwabi Ampofo of GLO all others who assisted me in diverse ways.

I am indebted to my mum Florence Dugble, my late dad Mr. Julius Atakpa and my uncle Mr. Samuel M.K Agblorti a lecturer at University of Cape Coast, department of Population and family life for their financial support, pieces of advices and encouragement.

Last but not the least to my siblings, I say a big thank you for your prayers, love and support.

TABLE OF CONTENTS

Content	Page
DECLARATION	i
DEDICATION	ii
ACKNOWLEDGEMENT	iii
TABLE OF CONTENTS.....	iv
LIST OF TABLE	ix
LIST OF FIGURES	xi
LIST OF PLATES	xii
LIST OF ABBREVIATION	xiii
ABSTRACT.....	xv
CHAPTER ONE	1
INTRODUCTION	1
1.1 Background	1
1.2 Statement of the Problem	4
1.3 Objectives.....	5
1.4 Relevance and Justification	5
1.5 Scope and Limitation	6
1.6 Organization of the Thesis	6
CHAPTER TWO	8
LITERATURE REVIEW	8
2.1 Introduction	8
2.2 Allocation of Frequency in Ghana	9
2.3 Types of Mobile Phone Base Station Antennas	10
2.3.1 Omni-directional antenna	10
2.3.2 Sector antenna.....	10
2.3.3 Mobile Phone Base Station.....	10

2.4 Quantities and Units.....	11
2.4.1 Dosimetric Quantities.....	13
2.5 Categories of Exposure.....	15
2.5.1 Occupational Exposure.....	15
2.5.2 Public Exposure.....	16
2.6 Antenna Field Pattern.....	16
2.6.1 Modulation.....	18
2.6.2 Polarization.....	19
2.7 Exposure Measurement.....	20
2.7.1 Exposure Zones.....	20
2.7.2 Analysis of site.....	22
2.8 Types of measurements.....	22
2.8.1 Narrowband measurement.....	22
2.8.2 Broadband Measurement.....	23
2.9 Measurement Uncertainty.....	24
2.9.1 Calibration factor.....	24
2.9.2 Antenna factor.....	25
2.10 Theoretical Estimation of Rooftop Base Station Antenna RF Exposure.....	26
(Ismail, et al, 2013).....	27
2.11 Standards for Limiting Exposure to Electromagnetic Fields.....	28
2.11.1 Guidelines of the International Commission for Non-Ionizing Protection (ICNIRP).....	28
2.11.2 FCC Exposure Guidelines.....	28
2.11.3 Time and Spatial Averaging.....	29
2.11.4 Standard of the Institute for Electrical and Electronic Engineers (IEEE).....	30
2.12 Occupational exposure to electromagnetic fields at RF transmitter sites.....	31
2.12.1 Assessment of radiofrequency/microwave radiation emitted by the antennas of roof top-mounted mobile phone base stations.....	32

2.12.2 Measurement and analysis of radiofrequency radiation from some mobile phone base stations in Ghana.....	33
2.12.3 Assessment of the levels of radiofrequency fields in the vicinity of FM radio stations in Accra, Ghana.....	34
2.12.4 Assessment of radiofrequency radiation within the vicinity of GSM base stations in Ghana.	34
2.13 Reviews of Studies on Health effects of RF fields.....	35
2.14 REVIEW OF STUDIES ON OCCUPATIONAL EXPOSURE	36
2.14.1 RF and Cancer.	36
2.14.2 Summary of Review	37
CHAPTER THREE	38
Materials and Methods	38
3. 1 Introduction	38
3.2 Sampling.....	38
3.3 Measurement instrumentation	40
3.4 Methodology	41
3.4.1 Measurement set-up.....	41
3.4.2 Measurement of coordinates.....	41
3.5 Determination and Documentation of the Test point(s).....	43
3.6 Measurement of electric field.....	43
3.6.1 Determination of Field strength.....	45
3.7 Measurement of coordinates	47
3.8 Uncertainty Estimation.....	47
3.9 Sample Calculations	49
3.9.1 Sample calculation of power density	49
3.9.2 Sample calculation of electric spatial average	49
3.9.3 Sample calculation of Exposure Quotient.....	50
3.9.4 Sample calculation of Uncertainty Estimation	51

CHAPTER FOUR.....	53
RESULTS AND DISCUSSION	53
4.1 Introduction	53
4.2 The Minimum and maximum electric field levels at the various rooftop base station sites.....	53
4.3 Spatial average electric field strengths inside and outside buildings at the various rooftop sites.	54
4.4 Calculated average power density levels inside and outside buildings at the various rooftop sites.	56
4.5 Exposure quotient for the rooftop base station sites.	57
4.6 Comparison of results with national and international standards.	59
4.7 Results for a typical tower mobile phone base station sites.	59
4.8 Comparison of results with other researched works.	60
4.9 Results of exposure quotients and calculated power densities at the various tower base station sites compared to international standard.	61
CHAPTER FIVE	63
Conclusions and Recommendations.....	63
5.1 Conclusions	63
5.2 Recommendations	64
5.2.1 Recommendation to National Communication Authority (NCA).....	64
5.2.2 Recommendation to Radiation Protection Institute (RPI) of GAEC.....	65
5.2.3 Management of Telecommunication Service Providers (TSP).	65
5.2.4 Occupationally Exposed Workers	66
5.2.5 Recommendation to the members of the Public.	66
5.2.6 Recommendation for Further Studies.....	66
REFERENCES	67
APPENDICES	70
APPENDIX A (Reference levels for public and occupational exposures).....	70

APPENDIX B (Electric field levels at each rooftop base station)..... 75

APPENDIX C (Spectral for ten different measurement point at rooftop base 4).....85

APPENDIX D (GPS coordinates and table of results for both rooftop and tower
base stations).....90

LIST OF TABLE

Table 2.1: Quantities and S.I units in the radiofrequency band (ICNIRP, 2009).....	14
Table A1: Typical sources of electromagnetic fields (Miller, 2002).....	70
Table A2: ICNIRP reference levels for occupational exposure (unperturbed rms values) (ICNIRP, 1998).....	70
Table A3: ICNIRP reference levels for general public exposure from the main telecommunications services and systems (WHO).....	71
Table A4: Maximum permissible exposures for people in controlled environment (IEEE, 2006).....	72
Table A5: FCC Limits for Maximum Permissible Exposure (MPE) for Occupational/Controlled Exposure (FCC, 1997).....	72
Table A6: Action level (maximum permissible exposure for the general public when an RF safety program is available) (IEEE, 2006).....	73
Table A7: Maximum permissible exposure action levels from the main telecommunication.....	74
Table A8: FCC Limits for Maximum Permissible Exposure (MPE) for General Population/Uncontrolled Exposure (FCC, 1997).....	74
Table B1: Measured electric fields at 10 locations at RBS 1.....	75
Table B2: Measured electric fields at 10 locations at RBS 2.....	75
Table B3: Measured electric fields at 10 locations at RBS 3.....	76
Table B4: Measured electric fields at 10 locations at RBS 4.....	76
Table B5: Measured electric fields at 10 locations at RBS 5.....	77
Table B6: Measured electric fields at 10 locations at RBS 6.....	77
Table B7: Measured electric fields at 10 locations at RBS 7.....	78
Table B8: Measured electric fields at 10 locations at RBS 8.....	78
Table B9: Measured electric fields at 10 locations at RBS 9.....	79
Table B10: Measured electric fields at 10 locations at RBS 10.....	79
Table B11: Measured electric fields at 10 locations at RBS 11.....	80

Table B12: Measured electric fields at 10 locations at RBS 12.....	80
Table B13: Measured electric fields at 10 locations at RBS 13.....	81
Table B14: Measured electric fields at 10 locations at RBS 14.....	81
Table B15: Measured electric fields at 10 locations at RBS 15.....	82
Table B16: Measured electric fields at 10 locations at RBS 16.....	82
Table B17: Measured electric fields at 10 locations at RBS 17.....	83
Table B18: Measured electric fields at 10 locations at RBS 18.....	83
Table B19: Measured electric fields at 10 locations at RBS 19.....	84
Table B20: Measured electric fields at 10 locations at RBS 20.....	84
Table 1: Shows the GPS coordinates of the various rooftop sites.....	90
Table 2: Maximum and minimum E-field strengths at the various rooftop sites.....	91
Table 3: Spatial averages of E-field strengths inside and outside buildings at the various rooftop sites.....	92
Table 4: Show the average power densities levels inside and outside at the various rooftop sites.....	93
Table 5: Exposure quotient of the general public and occupational inside and Outside buildings at the various rooftop sites.....	94
Table 6: Spatial average E-field strengths for various tower base station sites.....	95
Table 7: Exposure quotients and calculated power densities from the tower base Station sites.....	96

LIST OF FIGURES

Figure 2.1: Electromagnetic spectrum (FCC, 1997).....	12
Figure 2.2: Electromagnetic wave (FCC, 1997).....	12
Figure 2.3: Fields around an RF radiating source (ITU, 2003).....	17
Figure 2.4: Exposure zones at a radiating base station.....	21
Figure 3.1: Locations of rooftop base station one (1).....	39
Figure 3.2: Anritsu spectrum master MS2721B connected to PC.....	39
Figure 3.3: Shows the locations of 20 rooftop base stations in Accra.....	42
Figure 3.4: Spectrum for location 2 of rooftop base station one.....	45
Figure 4.1: A graph of maximum and minimum E-field strengths at the various rooftop sites.....	53
Figure 4.2: A graph of spatial average of E-fields intensities at the various rooftop sites.....	55
Figure 4.3: A graph of power density levels inside and outside buildings at the various rooftop sites.....	56
Figure 4.4: A graph of exposure quotients for public and occupational inside and outside buildings at the various rooftop base station sites.....	58
Figure 4.5: A graph of spatial average E-fields at the various tower base station sites.....	60

LIST OF PLATES

Plate 3.1: Spectrum analyzer in use with log periodic antenna.....	43
Plate 3.2: Site for rooftop base station twelve (12).....	44
Plate 3.3: Site for rooftop base station eleven (11).....	44

LIST OF ABBREVIATION

AM	-	Amplitude Modulation
AF	-	Antenna Factor
ANSI	-	American National Standard Institute
BRs	-	Basic Restrictions
CF	-	Calibration Factor
COMAR	-	Committee on Man and Radiation
DECT	-	Digital Electronic Cordless Telephone
ECC	-	Electronic Communications Committee
EMF	-	Electromagnetic Field
FCC	-	Federal Communications Commission of Engineering and Technology
FM	-	Frequency Modulation
GAEC	-	Ghana Atomic Energy Commission
GPS	-	Global Positioning System
IARC	-	International Agency for Research on Cancer
ICNIRP	-	International Commission on Non-Ionizing Radiation Protection
IEEE	-	Institute of Electrical and Electronic Engineers
ITU	-	International Telecommunication Union
IR	-	Infra Red
JOSE	-	International Journal of Occupational Safety and Ergonomics
MPE	-	Maximum Permissible Exposure
MW	-	Microwave
NCA	-	National Communication Authority

NCRP	-	National Council on Radiation Protection and Management
NIR	-	Non-Ionizing Radiation
PM	-	Phase Modulation
RF	-	Radio Frequency
RPI	-	Radiation Protection Institute
RBS	-	Rooftop Base Station
SA	-	Specific Absorption
SAR	-	Specific Absorption Rate
TBS	-	Tower Base Station
UHF	-	Ultra High Frequency
UMTS	-	Universal Mobile Telecommunication System
VHF	-	Very High Frequency
WHO	-	World Health Organization.

ABSTRACT

RF radiation exposure from antennas mounted on rooftop mobile phone base stations have become a serious issue in recent years due to the rapidly developing technologies in wireless telecommunication. The heightening numbers of base station and their closeness to the general public has led to possible health concerns as a result of exposure to RF radiations. The primary objective of this study was to assess the level of RF radiation emitted from roof top mobile phone base station antennas and compare the measured results with the guidelines set by International Commission on Non-ionization Radiation. The maximum and minimum average power density measured from the rooftop sites inside buildings were 2.46×10^{-2} and 1.68×10^{-3} W/m² respectively whereas that for outside buildings at the same rooftop site was also 7.44×10^{-5} and 3.35×10^{-3} W/m² respectively. Public exposure quotient also ranged between 3.74×10^{-10} to 1.31×10^{-07} inside buildings whilst that for outside varied between 7.44×10^{-10} to 1.65×10^{-06} . Occupational exposure quotient inside buildings varied between 1.66×10^{-11} to 2.11×10^{-09} whereas that for outside ranged from 3.31×10^{-09} to 3.30×10^{-07} all at the rooftop site. The results obtained for a typical tower base station also indicated that the maximum and minimum average power density was 4.57×10^{-1} W/m² and 7.13×10^{-3} W/m² respectively. The public exposure quotient varied between 1.58×10^{-09} to 1.01×10^{-07} whilst that for occupational exposure quotient ranged between 3.17×10^{-10} to 2.03×10^{-08} . The values of power densities levels inside buildings at rooftop sites are low compared to that of tower sites. This could be due to high attenuation caused by thick concrete walls and ceilings. The results obtained were found to be in compliance with ICNIRP and FCC guidance levels of 4.5 W/m² and 6 W/m² respectively.

CHAPTER ONE

INTRODUCTION

1.1 Background

Radiation is the energy that emanates from a source (e.g radiating antenna) and travel through space and may be able to penetrate various materials. It can also be said to be the propagation of energy through space in the form of waves or particles. Radiofrequency (RF) and microwave (MW) radiation are examples of a type of radiation called non-ionizing radiation (NIR). Non-ionizing radiation (NIR) refers to radiative energy that, instead of producing charged ions (ion pairs) when passing through matter, has sufficient energy only for excitation. Notwithstanding, it is known to cause biological effects. The NIR spectrum is divided into two main regions, optical radiation and electromagnetic fields. The optical radiation includes ultraviolet (UV), visible light and infra-red (IR). The electromagnetic fields also includes radiofrequency (RF), microwave (MW) and many more. NIR encompass the long wavelength greater than 100 nm (> 100 nm), low photon energy less than 12.4 electron-volt (eV) (< 12.4 eV) portion of the electromagnetic spectrum, and frequency from 1Hz to 3.0×10^{15} Hz. Radiofrequency (RF) has a frequency range of 300 Hz to 300 MHz whereas microwave radiation (MW) also has frequency range of 300 MHz to 300 GHz. In all, both the radiofrequency (RF) and microwave radiation operate in the frequency range 300 Hz to 300 GHz. (ICNIRP 2003).

Radiofrequency is employed in television transmitters, microwave ovens, mobile phones, telecommunication and radar/satellite links. RF is also employed in radio communication, television sets and visual displays units (VDUs). Some of the

medical application for RF includes microwave hyperthermia, therapeutic and surgical diathermy. (ICNIRP, 2003)

The sources of RF can be grouped as antennas whose dimension are less than the wavelength, those whose antennas dimensions are greater than the wavelength and sources producing leakage fields (examples includes radar components, RF dielectric heater, RF induction). The field surrounding an antenna is divided into two namely the near-field and far-field regions. Near field is a region that close to a radiating antenna or source that the fields are not plane waves in nature. This field usually vary more rapidly with distance or space. The near field is further divided in reactive (induction) near field and radiating near field. The induction near field region is portion of the near field that is surrounding the antenna where the reactive field prevails. This region is commonly assumed to extend to a distance of one wavelength from the antenna. At the boundary to the reactive near-field region, a transition region may be defined where the radiating field is beginning to be important compared with the reactive component. This outer region extends to a few wavelengths from the electromagnetic source. The radiating near-field (Fresnel) region is the area around field of an antenna between the reactive near- field and far-field region and where the radiation field prevails. Although the radiation is not propagating as plane wave, the electric and magnetic components can be considered as normal, i.e moreover the ratio $E/H=377\Omega$ can be assumed constant (and almost equal to Z_0 , the intrinsic impedance of free space). This region exists only if the maximum dimension D of the antenna is large compared with the wavelength (λ). The radiating far-field region of the field where the angular distribution is essentially independent of the distance from the antenna and the radiated power density (W/m^2) is constant.

The inner boundary of the radiating far-field region is defined by the larger 3λ and $2D^2/\lambda$ (i.e the limit is $2D^2/\lambda$ if the maximum dimension D of the antenna is large compared with the wavelength). In the far-field region the field components are transverse and propagate as a plane wave (ITU,2003).

The basic properties of electromagnetic fields (EMF) are related to the wavelength and polarization, characterized by near-field or far-field conditions of exposure. EMF in highly exposed work environments are usually near fields. Various physical estimators can be used for assessing EMF exposure at various frequencies. These includes internal measures of exposure effects in the body , related to thermal effects (specific absorption rate, SAR) and external measures of the exposure levels of the body, electric field strength (E), magnetic field strength (H), power density (S) and surface heating for high frequency. (JOSE, 2009).

RF field can induce current in poorly ground objects which flows through the human body to the ground as short circuit current. At low frequencies, there is (less than 100 MHz) the short circuit current runs through the body. There is tinkling and prickling sensations at frequencies lower than 100 MHz. At higher frequencies, there is a sensation of warmth which can lead to tissue damage.

On the 31st May, 2011, a press release numbered 208 from the World Health Organization (WHO)/International Agency for Research on Cancer (IARC) classifies radiofrequency electromagnetic fields as possibly carcinogenic to humans (group 2B) based on an increased risk for glioma, a malignant type of brain cancer associated with wireless phone use.

1.2 Statement of the Problem

Mobile phone base stations transmit their signal through radio waves. The widespread use of cell phones has raised public concerns about the health risks of exposure to radio frequency (RF) radiation from base station antennae. The antennae are usually mounted on towers or on rooftops of buildings. The antennae of these mobile phone base stations generate radio waves and they expose people near them to electromagnetic radiation. Health risks associated with RF radiation have become a global issue in recent times. In Ghana, there are six (6) telecommunication service providers who have mounted numerous mobile phone base stations throughout the country. Some of these base stations are mounted on rooftops of buildings. Base station antennae in Ghana transmit at RF frequencies of 900 MHz and 1800MHz. The signals from the antennae can be an important source of RF exposure particularly for people living in the vicinity of these base stations. Members of the public could be subjected to the similar exposure pattern inadvertently. The public tends to be agitated by possible hazards associated with exposure to RF radiation largely due to lack of sufficient information and scientific data.

Studies have shown that virtually much has not been done in this area in Ghana. This study is therefore aimed at assessing the level of RF exposure from rooftop mobile phone base station antennae. The study will also compare the RF emissions from roof-top antennae with those mounted on towers or masts. The study will help inform policy makers on the need to take RF radiation issues seriously in their decision making.

1.3 Objectives

The primary objective of this study is to assess the level of RF radiation emitted from rooftop mobile phone base station antennas and compare the measured results with guidelines set by International Commission on Non-ionizing Radiation Protection.

This study will also assess the exposure levels of the general public and also advance the understanding in this field.

The following are the specific objectives of this study:

- ❖ Measure the RF emissions from rooftop mobile phone base station antennae.
- ❖ Compare results of RF emissions from roof-top antennae with emissions from antennae mounted on tower or mast.
- ❖ To determine whether the power densities of both tower mobile base stations and rooftop mobile base stations are in compliance with standards set by relevant agencies like International Commission on Non Ionizing Radiation Protection (ICNIRP), Federal Commission on Communication (FCC) etc.

1.4 Relevance and Justification

The substantial growth in the use mobile phones has resulted in an increasing number of mobile phone base stations being built throughout the country. The growth is expected to continue with the recent launch of the third Generation (3G) mobile systems. Daily exposure to mobile phone base station electromagnetic field has raised public of possible health effects to people living in the vicinity of mobile phone base station antennas. Radiofrequency and microwave radiation exposure from the antennas from rooftop mobile phone base stations have become serious concern due to the rapid evolving technology in wireless telecommunication systems.

Hundreds of mobile phone base stations have been mounted through the country, some of which are mounted on rooftop. This growth comes with an unavoidable increase in the number of base stations sites, accompanied by public concerns due to the exposure to the members of the public. Assessment of the radiofrequency radiation from these installations have become necessary and important to limit the exposures to members of the public. It is expected that this research will provide some information on radiofrequency radiation exposure.

This will provide the basis for the assessment of exposure of the population living in the vicinity of these mobile phone base stations. This work will also help suggest guidelines for the control of radiofrequency radiation systems.

1.5 Scope and Limitation

Twenty (20) rooftop mobile phone base stations (RBS) and twenty (20) tower mobile phone base stations (TBS) from some selected part of the Greater Accra Region, Ghana will be used for this study. The selection of the base stations for assessment will include those located near densely populated localities such workplaces, markets, schools, etc and less populated areas.

Measurements would be taken at convenient locations starting from the rooftop, inside buildings and outside buildings or in the vicinities.

1.6 Organization of the Thesis

This thesis or research work has been arranged in the book as follows: in Chapter one, there are introductory notes on radiofrequency fields. Chapter two reviewed the state of other scholars work in the study area and some theories guiding the thesis area. Chapter three elaborates the procedures and equipment used in data collection.

In Chapter four, the data collected from the study will be analyzed and presented either in tables or graphs.

It will also discuss the relevance of the results obtained and their implications in relation to other published works. Chapter five will draw conclusions regarding the relevance of the study and make recommendations to organizations and for further study based on the results of this study.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

The growth in the electronics industry have led to the widespread use of radiofrequency (RF) devices in respective fields, including telecommunication, radio and television broadcasting, radar, medical application and consumer products. Electromagnetic fields (EMFs) covers over large fields when generated for communication, broadcasting and radar devices, but generally spreads only over small areas when used in industrial, medical and consumer devices. (Health Canada, 2009).

Before the end of the Second World War, safety practices to control the hazards from non-ionizing radiation (NIR) received little or no attention. (Cember & Johnson, 2009).

Notwithstanding, the post-war flourish in the electronics and communication, established on the microwave portion of the electromagnetic spectrum attracted the attention on the possible public health aspects of NIR. Cember & Johnson (2009) accounted that, it was in 1968 that Radiation Control for Health and Safety Act (Public Law 90-602) was passed by the U.S congress aimed at safeguard consumers from hazards related to electronic products. In 1970, Occupational Safety and Health Act [PL 91-596] was passed to safeguard workers from hazards, including ionizing and non-ionizing radiations.

Organization such as Federal Communication Commission (FCC), International Telecommunication Union (ITU), Institute of Electrical and Electronic Engineers (IEEE) have all furnished and advocated guidelines with the objective of protecting

members of the public and workers from the harmful effects of non-ionizing and ionizing radiations.

Other renowned organizations include the World Health Organization (WHO), National Council on Radiation Protection and Measurement (NCRP) and International Commission on Non-ionizing radiation (ICNIRP).

2.2 Allocation of Frequency in Ghana

The central body charged with the responsibility for licensing, allotting and regulating communication activities in Ghana is the National Communication Authority (NCA). Allocation of frequencies includes those used in navigation, marine, mobile communication, broadcasting and associated purposes. All these operations would have to be in compliance with national and international standards. They are also to ensure electromagnetic compatibility of all proposed or requested assignments with regards to existing assignments. The main objective of NCA is to regulate the provision of communication services in Ghana. In Ghana, mobile communication network providers operate with transmission frequencies of 900 MHz, 1800 MHz and 2100MHz. The 900 MHz is employed for mobile communication whereas the 1800 MHz is also employed for internet or data services. FM stations operate within the frequency band of 88 – 108 MHz. The television (TV) broadcasting stations typically operates in the ultra high frequency (UHF) band and very high frequency band. GSM, UMTS, DECT and bluetooth are examples of services employed in UHF. FM usually operates in the very high frequency (VHF). Each FM station is assigned a unique operating frequency to avoid interference.

2.3 Types of Mobile Phone Base Station Antennas

2.3.1 Omni-directional antenna

This type of antenna radiate RF energy equally in all directions in the horizontal plane. The antenna's input power is between 10-80 Watts and compliance boundary for a worker is 0.1-1.5 meters from the antenna. They usually long cylindrical rods which look like broomstick handles. They transmit radio signal at 360° horizontal direction.

2.3.2 Sector antenna

This type of antenna radiates most of its RF energy to a narrow angular sector in their forward direction (usually 60 to 120 degrees in the horizontal plane, normally 8 to 14 degrees in the vertical plane). The antenna input power is normally 10-80 Watts, with a compliance boundary for a worker is 0.2-3 meters from the front face of the antenna.

2.3.3 Mobile Phone Base Station

Mobile phone base stations are low-power radio transmitters that communicate with the user's handset. The mobile phone base station can transmit power levels greater than or equal to 100 W. (Schüz & Mann, 2000).

Radio and TV transmitters have broad coverage area and therefore operates at relatively high power levels up to 1 MW as compared base station transmitters. (Dahme, 1999).

Antennas of mobile phone base stations are more often than not around 15-30 cm in breadth and a few meters in length, depend on the frequency of operation.

Mobile phone base stations antennas are often installed on existing structures or roof tops of buildings at a height of 15 to 50 m from the earth surface .(MMF, 2008)

The main reason for installing antennas on roof tops of building is to minimize the visual impact of the facility and to use the available height to achieve coverage objectives and to minimize mobile phone coverage ‘black spots’. The antennas operate by transmitting a radio signal to provide coverage to a particular area. “Panel” antennas are most commonly used on roof tops. They are rectangular shaped antennas which direct the radio signal in a broad horizontal direction and a limited vertical direction. These antennas usually direct their power outward, in a beam that is most of the time very narrow in the vertical direction and but quite broad in the horizontal direction. The radio signal generated by the mobile phone base station antennas is referred to as radiofrequency electromagnetic energy (EME). (WHO, 2006).

2.4 Quantities and Units.

Radio frequency radiation is a portion of the electromagnetic spectrum. Fields generated by radio waves are usually quantified in terms of electric field strength (E) and magnetic field strength (H) (ICNIRP 2009).

On the electromagnetic spectrum radio waves or radio frequency radiation lies between the static frequency region and the infra-red region portion in the non-ionizing region of the electromagnetic spectrum. For purposes of radiation protection dosimetric quantities are required to describe sources and fields properties and to quantify the exposure to the human body. It also helps to estimate the energy absorbed in the human body

A picture of the electromagnetic spectrum is depicted in the figure below.

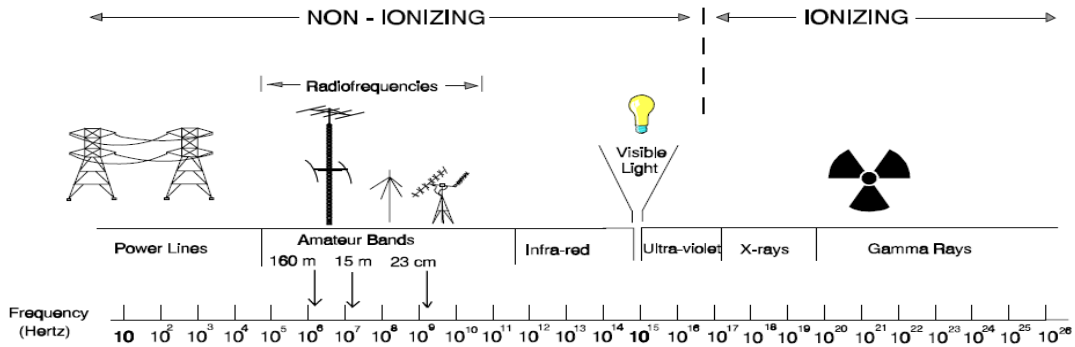


Figure 2.1: Electromagnetic Spectrum (FCC, 1997)

Electromagnetic waves and its related phenomena can be talked about in terms of radiation, energy or fields. Electromagnetic “radiation” is defined as waves of electric and magnetic energy moving together (i.e radiating) via space. This means the electric and magnetic fields are orthogonal to each other. Electric and magnetic fields are also perpendicular to the direction of propagation of the electromagnetic wave. The waves are generated by the movement of electric charges.

For example, the movement of charges in a radio station antenna (alternating current) creates electromagnetic waves that radiates away from the antenna and can be intercepted by receiving antenna. Electromagnetic “field refers to the electric and magnetic environment existing at some location due to a radiating source such as antenna (FCC, 1997).

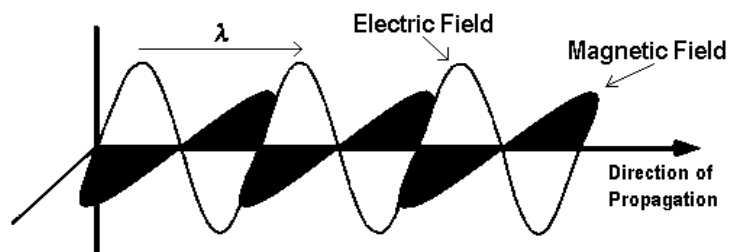


Figure 2.2 : Depicts the electromagnetic wave.(FCC 1997)

While magnetic fields are the consequences of the physical movement of electric charge, electric fields are related only with the presence of electric charge (ICNIRP, 2009).

For instance, when a power cord is plugged into a socket outlet (mains), it produces an electric field along the cord (Critical Review in Biomedical Engineering, 2003).

When a lamp is turned on, current flows through the cord and creates a magnetic field, the greater the current, stronger the magnetic field.

2.4.1 Dosimetric Quantities

The dosimetric quantity widely embraced is the specific absorption rate (SAR) which helps to estimate the energy absorbed in the human body. It is defined as the time derivative of the incremental energy, dW absorbed by or dissipated in an incremental mass, dm contained in a volume element dV of a given density, ρ .

$$SAR = \frac{d(dW)}{dt(dm)} = \frac{d(dW)}{dt(\rho dV)} \dots\dots\dots (2.1) \text{ (ICNIRP, 2009)}$$

The S.I unit of SAR is watt per kilogram ($W.kg^{-1}$).

Computation of SAR can also be done using the equation 2b.

$$SAR = \frac{E^2 \sigma}{\rho} \dots\dots\dots 2.2$$

Where σ is the conductivity of the body tissue in Simens per meter, E is the electric field strength in the body tissue in Volts per meter and ρ is the density of the body tissue in kilogram per meter cube (ITU, 2003)

ICNIRP acknowledges that the entity of a given effect of radio waves exposure is linked not only to the level of the external field, but also to the coupling of the field with the exposed body, or selected organs (ICNIRP, 1998). The effects, therefore, are better described by quantities that reflect the efficiency by which the external exposure causes a certain biological effect. These are termed biological effective quantities or dosimetric quantities. Many dosimetric quantities have been identified as appropriate for different interaction mechanisms and biological effects. Generally these quantities cannot be directly measured because they are internal to the body.

Table 2.1: Quantities and S.I units in the radiofrequency band (ICNIRP, 2009)

QUANTITY	SYMBOL	SI-UNIT	SYMBOL
Conductivity	Σ	Siemens per meter	$S.m^{-1}$
Permittivity	E	Farad per meter	$F.m^{-1}$
Current	I	Ampere	A
Current density	J	Ampere per square meter	$A.m^{-2}$
Electric field strength	E	Volt per meter	$V.m^{-1}$
Power density	S	Watt per square meter	$W.m^{-2}$
Frequency	F	Hertz	Hz
Impedance	Z	Ohm	Ω
Magnetic field strength	H	ampere per kilogram	$A.kg^{-1}$
Propagation constant	K	Per meter	m^{-1}
Specific absorption	SA	Joule per kilogram	$J.kg^{-1}$
Specific absorption rate	SAR	Watt per kilogram	$W.kg^{-1}$
Wavelength	Λ	Meter	M
Magnetic flux density	B	Tesla	T

The rudimentary limits for exposure to human are usually expressed as the specific absorption rate, SAR, specific absorption, SA, Current density (ITU, 2003). These rudimentary quantities are hard to quantify right away, virtually documents provide derived (reference) levels for magnetic field, electric field and power density.

Even though electric and magnetic field frequently happen together, most of the worry has been focused on the possible potential effects of magnetic fields. The fear is that it is very difficult to shield against magnetic fields. Another reason is that magnetic fields penetrate humans and buildings easily. However, electric fields have very little power to penetrate the human body or buildings (Critical Reviews in Biomedical Engineering, 2003).

2.5 Categories of Exposure.

Diverse international bodies such as IEEE, ICNIRP, ANSI, NCRP and FCC guidelines have recommended limits grouped into controlled/occupational exposure and uncontrolled/public (or general population) exposure. The limits was established on the power density (S) and specific absorption rate (SAR).

2.5.1 Occupational Exposure

It deals with situations in which persons are exposed as a consequence of their employment and in which those persons who are exposed have been made fully aware of the potential for exposure and can exercise control over their exposure (FCC, 2001). The awareness of the potential for radio frequency exposure in a controlled environment can be acquired through appropriate specific training. Warning signs and labels can be used to demonstrate such awareness.

They should give information in a spectacular manner, on the peril of potential exposure and directions on methods to minimize such exposure risk. It can be concluded that a controlled environment is one in which access is restricted.

2.5.2 Public Exposure

This type of exposure is a situation in which members of the public are exposed not as results of their employment (FCC, 2001). Generally, members of the public fall under this category when the exposure is not work related. An example is exposure to residents residing in proximity to a broadcasting or transmitting tower.

2.6 Antenna Field Pattern

The field around a radiating antenna is divided into two main parts namely the near-field and far-field regions. Near- field is a region that exists in proximity to a radiating antenna in which the electric and magnetic fields do not have a substantially plane-wave character but vary considerably from point to point. The far-field region is that region of the field of an antenna where the angular field distribution is essentially independent of the distance from the antenna. In the far-field region, the field has predominantly plane-wave character, i.e, locally uniform distribution of electric field strength and magnetic field strength in planes transverse to the direction of propagation. The near-field is further subdivided into the reactive (induction) and radiating near field regions. The reactive near-field region which is a portion of the near-field that is immediately surrounding the antenna and where the reactive field predominates. This region is commonly assumed to extend to a distance of one wavelength from the antenna. The reactive near-field, which is closest to the radiating structure and that contains most/nearly all of the stored energy.

Radiating near-field region is where the radiation field predominates over the reactive field, but lacks substantial plane-wave character and is complicated in structure. At the boundary to the reactive near-field region, a transition region may be defined wherein the radiating field is beginning to be important compared with the reactive component. This outer region extends to a few wavelengths from the electromagnetic source. The radiating near-field region is the region of field an antenna between the reactive near- field and far-field region and where the radiation field predominates. Although the radiation is not propagating as plane wave, the electric and magnetic components can be considered as normal, moreover the ratio E/H can be assumed constant (and almost equal to Z_0 , the intrinsic impedance of free space).

This region exists only if the maximum dimension D of the antenna is large compared with the wavelength (λ). The radiating far-field region of the field where the angular distribution is essentially independent of the distance from the antenna and the radiated power density (W/m^2) is constant. The inner boundary of the radiating far-field region is defined by the larger 3λ and $2D^2/\lambda$ (i.e the limit is $2D^2/\lambda$ if the maximum dimension D of the antenna is large compared with the wavelength). In the far-field region the field components are transverse and propagate as a plane wave (ITU, 2003).

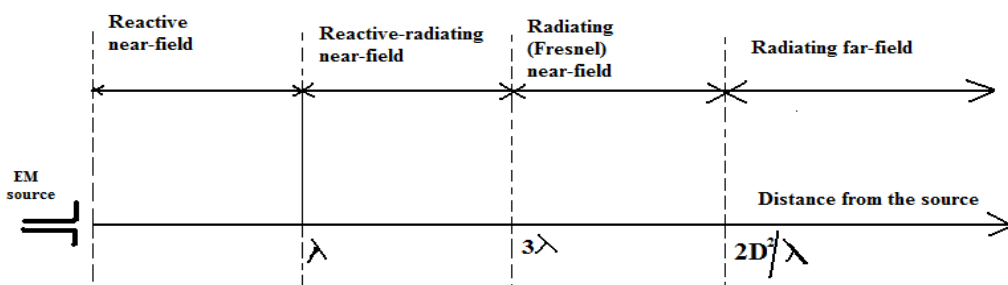


Figure 2.3 : fields around a RF radiating source (ITU, 2003)

2.6.1 Modulation

Modulation is said to be the process of changing one or more properties of a periodic waveform often called carrier signal (high frequency signal), with a modulating signal which typically contains information to be transmitted. It can also be depicted to be the process of conveying a message signal. For example a digital bit stream or an analog audio signal, inside another signal that can be physically transmitted.

Modulation of a sine waveform is used to transform a baseband message signal into a pass band signal. The device which helps in the performance of modulation is called a modulator.

According to the World English Dictionary (2008) radiofrequency modulation is depicted as varying the amplitude, frequency or other features of an electromagnetic wave or another carrier wave in order to transmit information.

Radio frequencies can be transmitted over long distances, but carry no information unless they are modulated. The modulating signal (i.e the data to be transmitted) is called the baseband. There are various forms of modulating a carrier signal. They include amplitude modulation, frequency modulation, phase modulation etc.

Amplitude modulation is where the modulating signal controls the signal level of the carrier. This can be accomplished by multiplying the modulating signal voltage and the carrier signal voltage together, this is known as mixing. Frequency modulation is where the frequency of the carrier signal increases and decreases and the voltage of the baseband signal rises and falls. This technique of modulation is non-linear, so harmonic of the baseband signal are produced and translated to either side of the carrier frequency. The amount of deviation of the carrier frequency relative to its center frequency is a measure of the modulation depth.

The greater the modulation depth, the greater the number of baseband harmonics generated and, consequently, the greater the bandwidth required. Whereas phase modulation is where the phase of the carrier is changed.

This method is related to frequency modulation and for a sine wave, the result is identical. The difference between them can be seen if a digital modulating signal is applied, because the phase of the carrier switches to its new value and produces a step change in carrier frequency (Steve Winder, 2001).

The human voice uses a frequency ranging from approximately 300 Hz to 3400Hz.

This is the reason why the ultra low frequency (ULF) band of the electromagnetic spectrum between 300Hz to 3000Hz is also referred to as voice frequency. The voice frequency is the electromagnetic energy that represent acoustic energy at baseband.

Whenever, these frequencies are transmitted directly as radiofrequency radiations, interference causes them to be ineffective.

Some other restriction of adequate significance is the virtual impossibility of transmitting low frequencies since the appropriate antennas for efficient propagation would be kilometers in length. Modulation is the solution thereof, which allows propagation of the low frequency intelligence with a high frequency carrier.

The electromagnetic waves transmitted have different wave forms. Continuous wave (CW) is considered the most rudimentary waveform.

2.6.2 Polarization

Polarization can be defined as the direction of oscillation of the electrical field vector. For mobile communication vertical polarization is used whereas broadcast systems use horizontal polarization. The polarization may be invariant in a particular direction

(linear polarization) or rotating (elliptical polarization). It is affirmed that electric field vector is always oriented in a given direction.

Hence it is called linearly polarized wave (ICNIRP, 2009). Whenever, electric field vector rotates around the direction of propagation, maintaining an invariant magnitude, it is said to be circularly polarized. Whenever, the extremity of the electric field vector draws an ellipse, it is said to be elliptically polarized. The rotation of the electric field vector happens in either clockwise or counter-clockwise.

It is affirmed by Health Canada (2009) that it is difficult to predict the orientation of the electric field in the near field region, as the transmitting antenna cannot be considered as a point source in this region.

In the far field region, the antenna becomes a point source, the electric and magnetic components of the field become orthogonal to the direction of propagation and their polarization characteristics do not vary with distance (Health Canada, 2009).

2.7 Exposure Measurement

Exposure assessment to electromagnetic field has the main aim to give information in order to implement a design for protecting individuals from exposure levels above recommended international standards. The exposure assessment could be done by computation or measurement. Usually both evaluations are done, computation first followed by the measurement (Cruz, 2009).

2.7.1 Exposure Zones

ITU, 2004 affirms that exposure assessment for all locations where people might be exposed to electromagnetic field (EMF) must be executed. The objective of such

exposure assessment is to categorize potential exposure to EMF as belonging to any of the three zones depicted in figure 2.4 below.

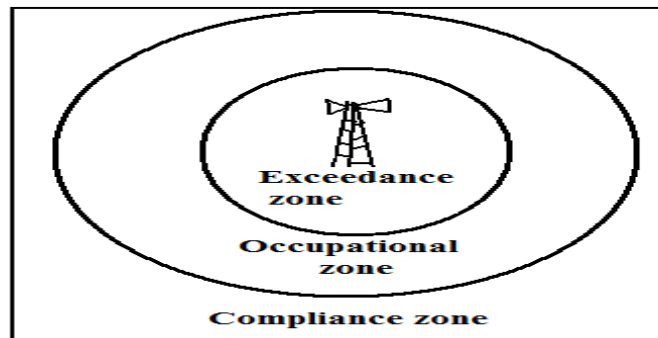


Figure 2.4 : Exposure zones at a radiating base station antenna.

1 Compliance zone: In this zone, potential exposure to EMF is below the limits for both controlled/occupational exposure and uncontrolled/general public exposure at the operation frequencies.

2. Occupational zone: In this zone, potential exposure to EMF is below the limits for controlled/occupational exposure but exceeds the limits for uncontrolled/general public exposure at the operation frequencies.

3 Exceedance zone: In this zone, potential exposure to EMF exceeds the limits for both controlled/occupational exposure and uncontrolled/general public exposure at the operation frequencies.

The occupational zone and exceedance zone are usually not easily accessible to people. They are only accessible to RF workers under special circumstances, such as a personnel standing directly in front of an antenna.

2.7.2 Analysis of site.

Sites to be quantified should be selected such that there are no reflecting objects and as few overhead conductors (power and telephone lines, antennas, buildings with metal roofs or gutters) as possible within ten times the wavelength.

It is necessary to clearly identify the measurement zones in order to restrict the measurements to only one of the components; electric (E) or magnetic (H) (Cruz, 2005).

2.8 Types of measurements

Consorting to the “Guidance on Complying with Limits for Human Exposure to Electromagnetic fields” (ITU-T Recommendation K.52) and the “Guidelines on the measurement and the numeric prediction of the electromagnetic fields for Compliance with Human Exposure Limits for Telecommunication Installations, Series K: Protection against Interference, (ITU-T Recommendation K.61) two types of measurements that could be carried out; namely the Narrowband measurement and Broadband measurement.

2.8.1 Narrowband measurement

Narrow-band devices are generally antennas with flat antenna factors over limited spectrum ranges (e.g., the dipole antennas) and can be used for frequency selective measurement (ITU-T Rec. K.61, 2003). Narrow-band measurements allow distinctions between the specific contributions in the different frequency ranges. They are based on the use of a spectrum analyser in association with one or several different antennas according to the frequency range to evaluate; tuned dipoles, biconal dipoles (30-300MHz, 20-600MHz, 250-1000MHz), log-periodic antennas (200-1000MHz), horn antennas (1-1.8GHz), double ridge waveguide horn antennas (1-

1.8GHz), among others. Spectrum analysers can detect signals being at least 8 to 10 orders of magnitude lower as the limits specified in the guidelines, standard or other document (Cruz, 2009).

The sensitivity of narrow-band devices is higher than broadband system and they are frequency selective so it is possible to identify the source of the non-compliance in case it is.

The equipment is however bulky, especially because of some antennas which are large and could be susceptible to wind load when mounted on a tripod (Cruz, 2005).

Most of the antennas are directional and have to be rotated or positioned at a number of orientations in order to ensure all of the signals are detected properly.

2.8.2 Broadband Measurement

The total contribution over a large frequency range is obtained without distinction of the contribution of different sources operating at different frequencies in broadband measurement. The broadband measurement is based on an electromagnetic field analyser controlled with its probe which could be controlled by a portable computer.

The exposure level could be given in rms or peak value in V/m, or W/m². Owing to their limited sensitivity, broadband meters are often used for compliance assessment (Cruz, 2005).

Broadband devices (such as the commonly used electric and magnetic probes) do not give information on frequency spectrum. The probes consist generally of short-electrical dipoles (or loops) that detect the field. The corresponding current flows through a conductor wire (with high resistance). Isotropic probes measure the field components in the three orthogonal directions in space and calculate the magnitude of the resultant field strength and thus facilitate the assessment procedure.

2.9 Measurement Uncertainty

The main sources of uncertainty are electric factors and factors arriving from measurement practices (Cruz, 2009).

Electrical factors are associated to the calibration of the field analyser and antennas. Practice factors measurement comes up because during measurement the antennas are mounted on tripod stands.

Measurement includes rotations or position which could result in extra uncertainty because of the coupling of positioning linked to fixed structures in the vicinity or operator's body.

2.9.1 Calibration factor

For broadband probes the calibration factor, CF, is defined by the following formula:

$$CF = \frac{E_{ref}}{E_{meas}} \dots\dots\dots 2.3$$

It is the ratio between the expected electric reference field strength (E_{ref}) and the value (E_{meas}) read on the PC or on a dedicated receiver unit. This factor is mainly a function of frequency and, in the presence of non-linearity error, of field strength.

The CF is determined as a frequency function. For each frequency, the CF value shall be known with uncertainty less than 1 dB. Errors due to frequency interpolation are included in the tolerable uncertainty on CF (ITU-K.61, 2003).

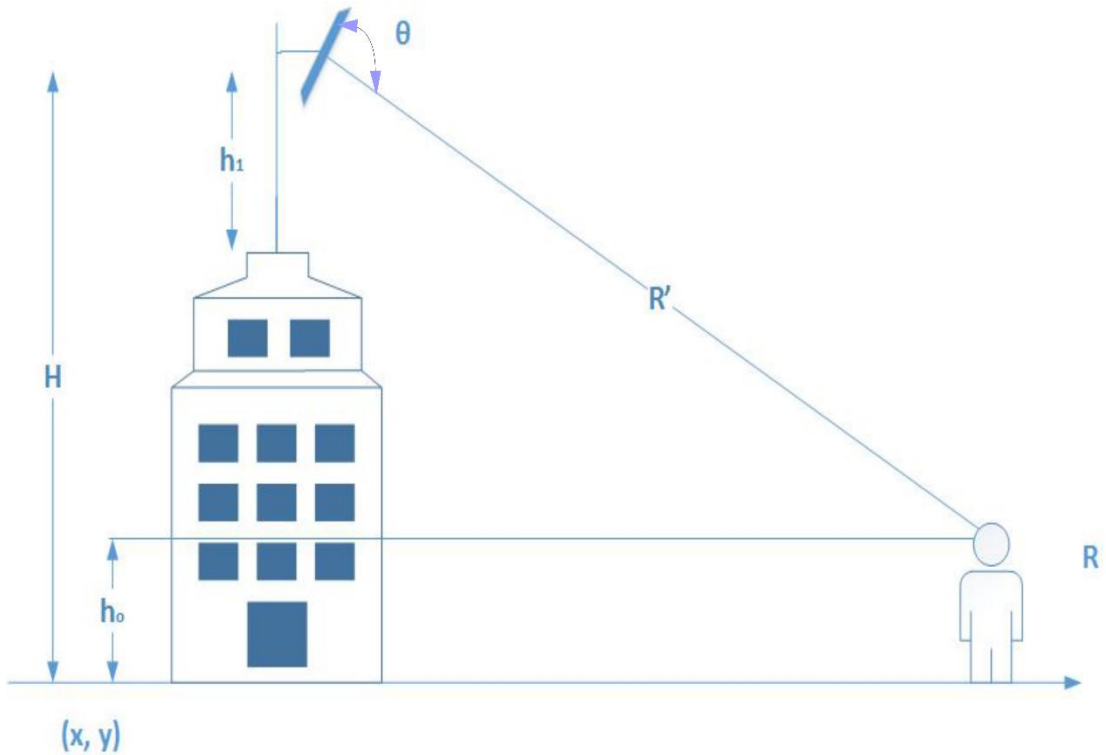
2.9.2 Antenna factor

The antenna factor (A_k) is defined for antennas and frequency selective probes as the ratio:

$$A_k = \frac{E_{ref}}{V} [m^{-1}] \text{-----} 2.4$$

Where E_{ref} [V/m] is the electric field strength on the probe and V [V] is the voltage measured on the spectrum analyzer. This factor is primarily a function of frequency but, in presence of non-linearity error, it may depend on field strength, too. The A_k is determined as a frequency function. For each frequency, the A_k value shall be known with an expanded uncertainty (i.e., 95% statistical confidence) of less than 2 dB. The maximum tolerable uncertainty includes also the error due to frequency interpolation (when needed) (ITU, 2003).

2.10 Theoretical Estimation of Rooftop Base Station Antenna RF Exposure.



With known observation height, h_o , antenna height, h_1 and building height, H given, the real distance R' can be determined by:

$$R'^2 = (H - h_1 - h_o)^2 + R^2 \dots\dots\dots 2.5$$

And by using Pythagorean Theorem the real distance, R' is established by:

$$R'^2 = (H - h_1 - h_o)^2 + (x-x_i)^2 + (y-y_i)^2 + R^2 \dots\dots\dots 2.6$$

Where $i \in \{1, 2, \dots, n\}$. The elevation angle, θ in this case is formulated by the equation.

$$\theta = \pi - \tan^{-1} \left(\frac{H - h_o - h_1}{x} \right) \dots\dots\dots 2.7$$

The power density in W/m^2 for S equation due to a point in a free space far field region in relation to 2.5 is specified as:

$$S = \frac{PG}{4\pi R'^2} = \frac{PG}{4\pi[(H-h_o-h_1)^2 + (x-x_i)^2 + (y-y_i)^2]} \dots\dots\dots 2.8$$

Where,

S = Power density (W/m²)

H = Height of structure or building

h_o = Observation height

h₁ = Height of the antenna

R = Distance from the antenna

R' = Real distance from antenna to the observation height.

θ = Angle of elevation of the antenna.

P = Power

G = Gain of the antenna

(x,y) = Coordinate relative to a certain origin

(Ismail, et al, 2013)

2.11 Standards for Limiting Exposure to Electromagnetic Fields

2.11.1 Guidelines of the International Commission for Non-Ionizing Protection

(ICNIRP)

The guidelines set by ICNIRP are the most widely recognized guidelines for non-ionizing radiations. They are certified by renowned organizations such as the World Health Organization (WHO), the International Telecommunications union (ITU) and by more than 30 countries worldwide including health administrations and environmental organizations. These guidelines are given as a function of basic restrictions and reference levels and are a two-tier system made up of general public and occupational exposure limits. The basic restrictions are physical parameters which are necessary to assure that there will not be any adverse effect, but they are difficult to measure in the field. Hence the basic restrictions are related to the reference levels which are easy to measure at field and are obtainable from the basic restrictions by using computational models and measurement methods.

2.11.2 FCC Exposure Guidelines

The FCC's guidelines for Maximum Permissible Exposure (MPE) are defined in terms of power density electric field strength (units of volts per meter: V/m) and magnetic field strength (units of amperes per meter: A/m). The FCC guidelines incorporate two separate tiers of exposure limits that are dependent on the situation in which the exposure takes place and/or the status of the individuals who are subject to exposure. The decision as to which level applies in a given situation should be based on the application of the definitions of controlled/occupational and uncontrolled/general population exposures (FCC, 1997).

In the far-field, in free space of a transmitting antenna, where the electric field vector (E), the magnetic field vector (H), and the direction of propagation can be considered to be all mutually orthogonal ("plane-wave" conditions).

2.11.3 Time and Spatial Averaging

A fundamental aspect of the exposure guidelines is that they apply to power densities or the squares of the electric and magnetic field strengths that are spatially averaged over the body dimensions. Spatially averaged RF field levels most accurately relate to estimating the whole-body averaged specific absorption rate (SAR) that will result from the exposure are based on this concept. This means that local values of exposures that exceed the stated MPEs do not imply non-compliance if the spatial average of RF fields over the body does not exceed the MPEs. Further discussion of spatial averaging as it relates to field measurements can be found in Section 3 of Bulletin 65 and in the ANSI/IEEE and NCRP reference documents noted there (FCC, 1997) .

Another feature of the exposure guidelines is that exposures, in terms of power density, E^2 or H^2 , may be averaged over certain periods of time with the average not to exceed the limit for continuous exposure. The averaging time for occupational/controlled exposures is 6 minutes, while the averaging time for general population/uncontrolled exposures is 30 minutes. It is important to note that for general population/uncontrolled exposures it is usually not possible or practical to control access or otherwise limit exposure duration to the extent that averaging times can be applied. In those situations, it would normally be necessary to assume continuous exposure to RF fields that would be created by the on/off cycles of the radiating source.

One relevant point to remember concerning the FCC's exposure guidelines is that they constitute exposure limits (not emission limits), and they are relevant only to locations that are accessible to workers (or members of an amateur's household) or members of the public.

Such access can be restricted or controlled by appropriate means such as the use of fences, warning signs, etc., as noted above.

For the case of occupational/controlled exposure, procedures can be instituted for working in the vicinity of RF sources that will prevent exposures in excess of the reference levels in the guidelines. An example of such procedures would be restricting the time an individual could be near an RF source or requiring that work on or near such sources be performed while the transmitter is turned off or while power is appropriately reduced.

2.11.4 Standard of the Institute for Electrical and Electronic Engineers (IEEE)

The IEEE Standard for Safety Levels with Respect to Human Exposure to Radio Frequency Electromagnetic Fields, 3kHz to 300GHz are aimed at protecting people against established adverse health effects in human beings linked to electric, magnetic and electromagnetic fields in the frequency range 3kHz to 300GHz. These recommendations are expressed in terms of basic restrictions (BRs) and maximum permissible exposure (MPE) values and are a system of two tiers consisting of action level and controlled -environmental exposure limits. These recommendations are not intended for the purpose of preventing interference with medical and other devices that may exhibit susceptibility to RF fields. The basic restrictions are exposure restrictions to electromagnetic fields based on the established health effects. The maximum permissible exposure values are derived from basic restriction and are limits on external fields and both induced and contact current.

Both the basic restrictions and the MPE values incorporate safety factors that take into account uncertainties. They provide a margin of safety for all. It is possible to exceed an MPE while still complying with basic restrictions because generally, the safety factors incorporated in the MPEs are greater than the safety factors in the basic restrictions (IEEE, 2006).

2.12 Occupational exposure to electromagnetic fields at RF transmitter sites.

Evaluation of radio waves and radiofrequency electromagnetic fields exposure have been done in order to investigate the range of exposures received by workers in the telecommunications, broadcast, and air traffic control industries (Cooper et al, 2007). Investigation at various sites using both portable survey equipment (hazard survey meters) and personal exposure monitors. The quantitated electric field strength using the two types of equipment ordinarily corresponded to within manufacturer's specified uncertainties when the user in the direction of source of exposure, providing the measurement location was not in area where the spatial distribution of the field was highly non-uniform (Cooper et al, 2007). The quantitation were done in the near field of the radiating antennae. The electric fields quantitation were taken at seven sites employed for broadcasting television and FM radio signals. Each site hosted a number of telecommunications systems such as base stations for mobile phone and wide area paging networks and point-to-point microwave links. The antennas at most of the sites were mounted on self-supporting towers or masts. These had ladders running up inside them and maintenance platforms were located at regular intervals. The quantitated electric field strength in the vicinity of UHF television antennas are as follows: 60-100 Vm^{-1} in between two array; and 10-90 Vm^{-1} at the top platform just below the main analogue array; and 20-30 Vm^{-1} in the digital array.

The measured electric field in the vicinity of VHF broadcast radio antennas are; 50-100 Vm^{-1} on the platforms above the main array(four channels); 20-80 Vm^{-1} on the platform beneath the main array and 20-400 Vm^{-1} inside the main array.

2.12.1 Assessment of radiofrequency/microwave radiation emitted by the antennas of roof top-mounted mobile phone base stations.

Assessment of radiofrequency radiation from roof top mobile phone base stations has been conducted in some parts Malaysia. Man & Shahidan, 2005 reported a study of EM radiation at public access points in the vicinity of 200 sites around 47 mobile phone bases in Malaysia. Man & Shahidan indicated that the chosen sites were selected to encompass those in the densely populated areas as well as less densely populated areas. The locations of the base stations were noted and divided into two categories, i.e those situated within and greater than 200 m from dwellings or houses. Measurements were made at public access locations at all the sites.

The primary objectives of the study was to to measure and analyze the electromagnetic field strength levels emitted by roof top mobile phone base station antennas mounted by MAXIS and DIGI wireless communication service providers and to assess the level of compliance with standards set by the International Commission on Non-ionizing Radiological Protection (ICNIRP) and other international regulatory bodies. A digital RF analyzer HF35C was employed for the study.

All measurement were carried out during the daytime from 8.00 am to 12.00 noon in May and June, 2005. The measurement were also repeated in the increments of 10 m distance in each measurement. Results obtained from showed that the power density varied both space and time. There were large fluctuation in the readings at every sites and measurement. There were also large discrepancy between the maximum and

minimum values at every site. The RF radiation directly beneath the base station antennas was not always close to zero. Some could reach $200\mu\text{Wm}^{-2}$ (Man & Shalidan, 2005). Man & Shahidan stated that results obtained from all the base stations were well below the maximum exposure limits set by various agencies.

2.12.2 Measurement and analysis of radiofrequency radiation from some mobile phone base stations in Ghana.

Amoako et al, (2009) report a survey of the radiofrequency electromagnetic radiation at public access points in the vicinity of 50 cellular phone base stations in Ghana. Amoako et al, (2009) pointed out that “the selected sites were chosen to cover those close to schools, hospitals and highly populated residential areas”. Measurements were made at public access locations at all the sites.

The primary objective was to measure and analyse the electromagnetic field strength levels emitted by antennae installed and operated by the Ghana Telecommunications Company and to assess the level of compliance with standards set by the International Commission on Non-ionizing Radiation Protection (ICNIRP) and other international regulatory bodies (Amoako et al, 2009). An Anritsu model MS 2601A hand held spectrum analyser was used.

The results of field measurements at various cell sites used for this study show power density variation of as low as $0.01\ \mu\text{W m}^{-2}$ to as high as $10\ \mu\text{W m}^{-2}$ for the frequency of 900 MHz. At a transmission frequency of 1800 MHz, the variation of power densities is from 0.01 to $100\ \mu\text{W m}^{-2}$ (Amoako et al, 2009). Even though the ground level power densities were below the limits recommended by RF safety standards, the results however shows that in some cases the power densities measured are much higher (about 20 times higher) than typical values measured in other studies in the

UK, Australia and the USA. Amoako et al, (2009) stated that "these results are quite important and give room for serious concern as the number of mobile phone users increases without a corresponding increase in the number of base stations. Emission levels are bound to go higher. There is a need to increase the number of cell sites in order to improve the quality of signal received at a lower antennae power level".

2.12.3 Assessment of the levels of radiofrequency fields in the vicinity of FM radio stations in Accra, Ghana.

Azar et al, (2011) report a survey of the radiofrequency electromagnetic radiation at public access points in the vicinity of twenty FM radio stations in Accra, Ghana. The rudimentary objective was to determine the levels of RF fields from FM broadcast antennae and to assess the extent of exposure to members of the public and workers to RF from FM stations installations. The outcomes obtained indicated that the levels of electric field strength ranged from $3.1\text{E-}04 \pm 6.3\text{E-}06$ V/m at Sweet Melody FM to $7.4\text{E-}08 \pm 1.6\text{E-}08$ V/m at Channel R FM. Occupational exposure quotient ranged between $5.1\text{E-}06$ V/m and $1.2\text{E-}09$ V/m whereas the general public exposure quotient varied from $1.1\text{E-}05$ V/m to $2.6\text{E-}09$ V/m. At a transmission frequency range of 88 – 108MHz, the variation of power densities is from $2.5\text{E-}10$ to $1.5\text{E-}17\text{W/m}^2$. These values are below the reference level set by the International Commission on Non-ionizing Radiation Protection.

2.12.4 Assessment of radiofrequency radiation within the vicinity of GSM base stations in Ghana.

Deatanyah et al, (2011) report a survey of the radiofrequency electromagnetic radiation safety at public access points in 46 towns with 76 Global system for Mobile Communication (GSM) cell sites in two major cities in Ghana. Deatanyah et al,

(2011) pointed out that the selected cell sites were chosen to represent those located near residential areas, schools and market places. Quantitation were made at public access locations at all the sites. The primary objective was to determine the levels of RF field in a residential areas, schools and market places and compare the measured results with the guidelines set by International Commission on Non-ionizing Radiation (ICNIRP) (Deatanyah et al, 2011).

Measurements were made with a log-periodic antenna coupled with spectrum analyser. The results varied from 0.85 to 1.07 mWm^{-2} and 0.78 to 1.19 mWm^{-2} for the transmission frequencies of 900 and 1800 MHz respectively. The results more often than not shows compliance with the International Commission on Non-ionizing Radiation Protection. (ICNIRP) limit of 0.024% but 108 times higher than a similar survey carried out in Ghana two (2) years ago.

2.13 Reviews of Studies on Health effects of RF fields.

All established health hazards to people associated with RF fields occurs at exposure levels that cause heating of the body tissues.

The resulting temperature elevation depends on how well the body can dissipate the excess heat. In high intensity exposure situations RF heating can be sufficient to overcome the body's cooling ability and results in tissue damage. Tissue with a poor blood supply are particularly vulnerable. In the case of the lens of the eyes, which has no blood supply, cataract can result from high intensity exposures that raise the temperature of the lens by more than a few degrees. However, the circumstances that give rise to such effects are very rare and confined to occupational environments where an accidental over-exposure may occur (COMAR, 2002).

According to the Expert Group on health effects of EM fields (2005), studies involving animals and humans volunteers have found that adverse health effects are

observed only when the heating produced by RF exposure raises tissue or body temperature by more than about 1°C. Induced heating of this magnitude may provoke various physiological and thermoregulatory responses, including a decreased ability to perform certain tasks. The effects are similar to those experienced by people working in hot environments or suffering a prolonged fever.

The development of the foetus may also be affected by induced heating, and birth defects could occur if the foetus' temperature were raised by 2-3°C for a number of hours. Induced heating can also affect male fertility and, as described above, cause cataracts.

It is quite unlikely, however, that a member of the public would ever be exposed to field strengths of the magnitude necessary to produce such significant heating (WHO, 1998). From over 1300 peer reviewed scientific studies published since 1945 reveals that a consistent and clear conclusion that adverse health effects arise only where the absorption of RF energy generates a rise in temperature that cannot be accommodated by the body's cooling system. This conclusion has been supported by recent national reviews of RF health effects undertaken in a number of countries.

2.14 REVIEW OF STUDIES ON OCCUPATIONAL EXPOSURE

2.14.1 RF and Cancer.

On the 31st May, 2011, a press release numbered 208 from the World Health Organization (WHO)/International Agency for Research on Cancer (IARC) classifies radiofrequency electromagnetic fields as possibly carcinogenic to humans (group 2B) based on an increased risk for glioma, a malignant type of brain cancer associated with wireless phone use (IARC, 2011). Group 2B category is used for agents for which there is limited evidence of carcinogenicity in humans and less than sufficient

evidence of carcinogenicity in experimental animals. It may also be used when there is inadequate evidence of carcinogenicity in humans but there is sufficient evidence of carcinogenicity in experimental animals. In some instances, an agent for which there is inadequate evidence of carcinogenicity in humans and less than sufficient evidence of carcinogenicity in experimental animals together with supporting evidence from mechanics and other relevant data may be placed in this group. An agent may be classified in this category solely on the basis of strong evidence from mechanistic and other relevant data.

2.14.2 Summary of Review

In spite of the fact that results so far are inconclusive on acute health effects and no adverse health effects have been established below international reference levels, precautionary measures should be taken to reduce exposure to the general public.

This makes it important to assess the levels that the public is exposed to and find means of keeping down the levels which this work seeks to achieve.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Introduction

This chapter depicts the materials and methods employed during the thesis work and field measurement taken during the peak periods of the rooftop mobile phone base station installations.

3.2 Sampling

Twenty (20) roof top mobile phone base stations and twenty (20) tower mobile phone base stations scattered over the Greater Accra Region, Ghana were selected out of the numerous existing rooftop base stations and tower base stations. Information on the location was furnished by the National Communication Authority (NCA). Table 3.1 indicates the 20 roof top base stations and their locations. The selection was done so that the sample space is a representative of how rooftop base stations are sited in the country. Some rooftop base stations are installed on top of residential buildings, corporate buildings, whilst others are installed on commercial plazas. Virtually all the rooftop base stations chosen are situated along Accra's most officious streets, surrounded by commercial and residential accommodations. Fig 3.1 indicates where the 20 rooftop base stations sites can be found within the Greater Accra Region.

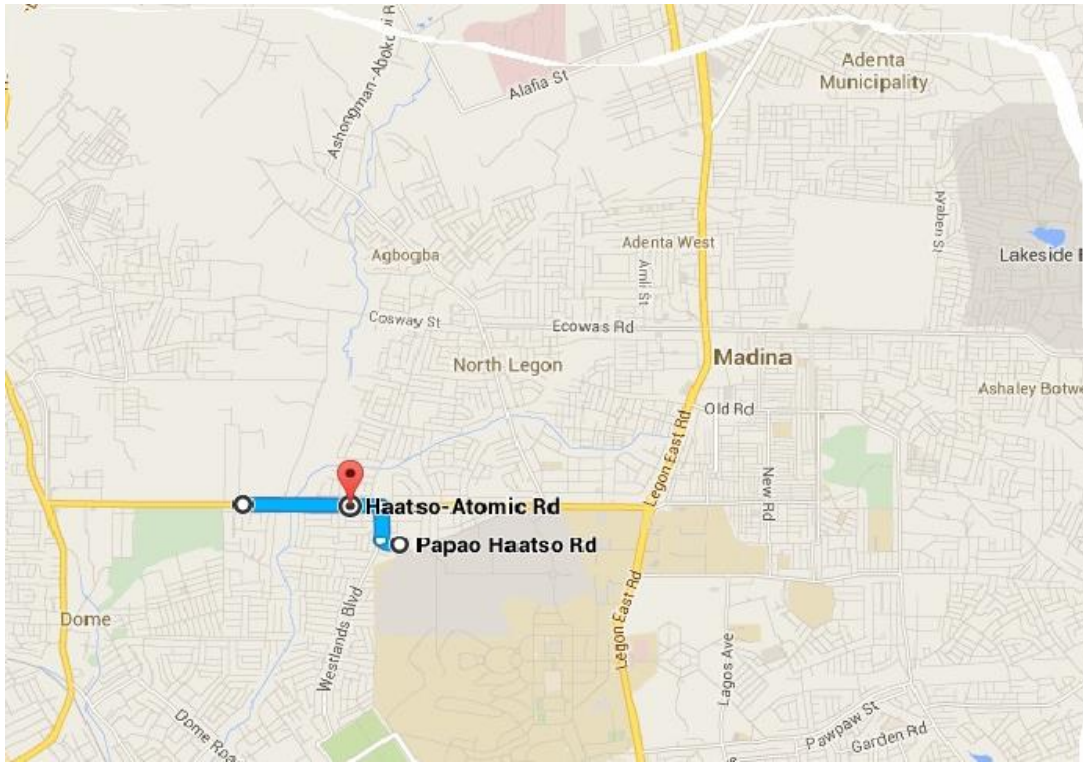


Figure 3.1 Location of rooftop base station site one (1).

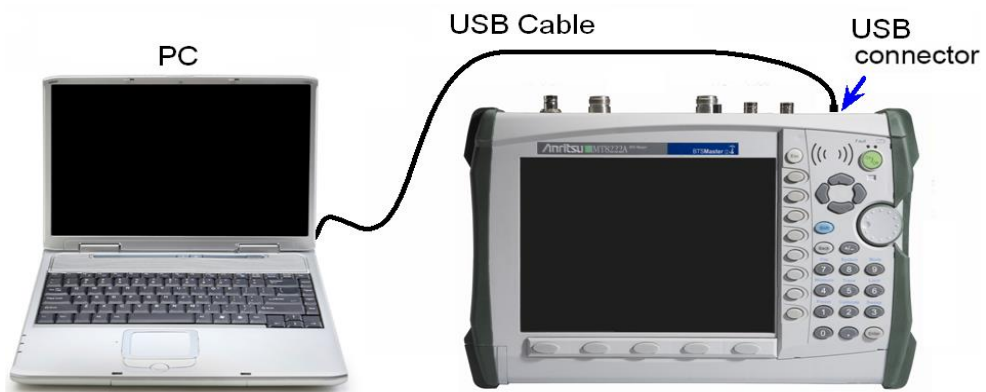


Figure 3.2 Anritsu Spectrum Master MS2721B connected to PC.

3.3 Measurement instrumentation

A type of spectrum analyzer called Anritsu Spectrum Master for RF and Microwave Handheld Instruments with model number MS2721B and serial number 0940037 was employed for the study. It is frequency selective and measures the electric or magnetic field strength from one or more sources in a “narrow” frequency band. Anritsu Spectrum Master displays and/or records the field strength versus frequency through the frequency range of interest. The spectrum master is sensitive to RF within the range 9 kHz – 7.1GHz. The spectrum master was coupled with an Anritsu log-periodic antenna with model number MP666A and serial number 6200849238 using an RF cable and mounted on a non-conductive tripod stand to prevent perturbation of the electromagnetic fields. The tripod stand was then mounted at an average height of 1.5m from the ground.

The Anritsu log-periodic antenna with model number MP666A had a frequency range from 200 MHz to 2 GHz. It has a Voltage Standing Wave Ratio (VSWR) ≤ 2.0 and Gain of 7.15 dBi. The antenna cable used was a lead shield coaxial cable which was matched to the receiver input impedance as well as the antenna load impedance. The load impedance was 50 Ω . The log periodic antenna was mounted on a non-conductive antenna tripod.

A Global Positioning System (GPS) Garmin GPS map 62 was employed to record the coordinates of the locations of the measurement points. The instrument set was obtained from The Radiation Protection Institute of the Ghana Atomic Energy Commission located at Kwabenya, Accra.

3.4 Methodology

3.4.1 Measurement set-up

The Anritsu log-periodic antenna with model number MP666A and serial number 6200849238 which operates within the frequency range of 200 MHz to 2 GHz was mounted on a non-conductive tripod stand to prevent perturbation of the electromagnetic fields and coupled to a spectrum analyser called Anritsu Spectrum Master MS2721B using an RF cable. The Spectrum analyzer was booted and the appropriate parameters set up; Bandwidth (BW) = 100 kHz with a sweep time of 700ms, frequency span, Attenuation level (dBm) and scale as appropriate. The set up was permitted about five minutes to warm up, within which time the personnel positioned themselves about three meters behind the Anritsu log-periodic antenna, with the antenna pointing the direction of the radiating rooftop base station antenna. Fig 3.2a indicated the Anritsu Spectrum Master MS2721B with PC. The tripod stand was then mounted at an average height of 1.5m from the ground. Majority of the rooftop mobile base stations had not less than three (3) sector antennas installed on them, a sector antenna covers 120° sector area. Therefore the three sector antennas will cover a sector area of 360°.

3.4.2 Measurement of coordinates

For the study to be quotable, a global positioning system (GPS) named Garmin GPS map 62 manufactured by Garmin Company was used to record the coordinates of the measurement points of the respective rooftop base stations and also for locating the locations the base stations.



Source: Global Map

Figure 3.3 shows the locations of the rooftop base stations sites in Accra.

3.5 Determination and Documentation of the Test point(s).

Measurement points within the locality of the rooftop base station installations were ascertained based on the plan or design of the sites. Measurement points were chosen to represent the highest levels of exposure to which a person might be subjected, considering the positions of the antennas. Measurement sites were selected so that there are no reflecting objects and as few overhead conductors (power and telephone lines, antennas, buildings with metal roofs or gutters) as possible. These locations were found by a quick check using measuring equipment. The measurement was made for a single point, 1.5 m above ground (or floor) level.

3.6 Measurement of electric field



Source: Field work 2014

Plate 3.1: Spectrum Analyser in use with log periodic antenna.



Plate 3.2: Site for rooftop base station twelve (12)



Plate 3.3: Site for rooftop base station eleven (11)

The Anritsu log-periodic antenna was rotated in various directions until the maximum peak was noticed on the spectrum analyser. The transmitter signal was recorded over a six minutes period as a DAT file on the Spectrum master. Fig 3.5 exhibits a sample DAT file for rooftop site location ‘1’

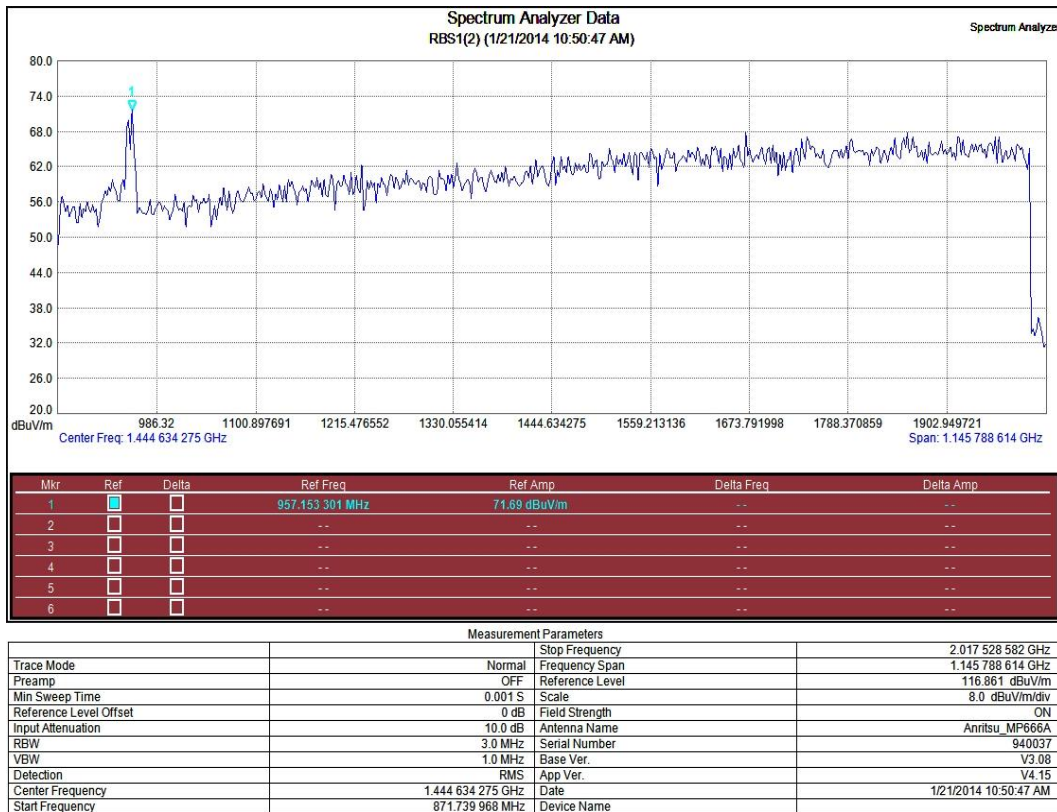


Figure 3.4 Spectrum for location ‘2’ of rooftop base station one (RBS 1)

3.6.1 Determination of Field strength

The highest peak corresponding to the frequency of interest is marked using Master Software Tools. The scale on the spectrum analyser was altered so as to record the equivalent amplitude in units of dBμV/m. The electric field strength was obtained by converting the field strength from dBμV/m to V/m employing equation 3.1

$$E (V/m) = 10^{\left(\frac{F-120}{20}\right)} \dots\dots\dots \text{equation 3.1}$$

Where F= field strength level in dB μ V/m

E= Electric field strength in V/m.

The power density at each location was calculated using equation 2.9 (FCC, 1997).

$$S = \frac{E^2}{377} = 377H^2 \dots\dots\dots 3.2$$

where S = power density (W/m²)

E = electric field strength (V/m)

H = magnetic field strength (A/m)

For the level of compliance, the ratio E_{meas}/E_{icnirp} was calculated for each location as well as facility, where E_{meas} is the value determined from equation 3.3 and E_{icnirp} is the value of existing maximum permissible emission level set by ICNIRP. Spatial average electric field strength values were calculated for each rooftop base station and a graph of electric field strength against stations were plotted. The spatial average electric field strengths were calculated from equation 3.4.

$$E_{spatial_average} = \sqrt{\frac{\sum_{i=1}^n E_i^2}{n}} \dots\dots\dots 3.3$$

3.7 Measurement of coordinates

For repeatability of study, Global Positioning System (GPS) named GPSmap 62 manufactured by the Garmin Company was used to record coordinates of the measurements points and location of the various base stations.

3.8 Uncertainty Estimation

The measurement uncertainty was assessed for the electric field measurements taking into consideration each of the the various sources of uncertainty in the measurements .The standard uncertainty $u_{(x_i)}$ and the sensitivity coefficient c_i was evaluated for the estimate x_i of each quantity. In this case $c_i = 1$. The combined standard uncertainty $U_c(E)$ of the estimate E of the measurand is calculated as a weighted root sum square (r.s.s.):

$$U_c(E) = \sqrt{\sum_{i=1}^n (c_i * u_{(x_i)})^2} \dots\dots\dots 3.4$$

The combine standard uncertainty $U_c(E)$ was first found by calculating the estimated standard deviation S , which is given by the expression

$$S = \sqrt{\frac{\sum_{i=1}^n (x_i - \bar{x})^2}{n-1}} \dots\dots\dots 3.5$$

Where $\bar{x} = \frac{\sum_{i=1}^n x_i}{n}$ is the mean of the verification checks and n is the total number

of samples. The standard uncertainty $u_{(x_i)}$ was calculated using the formula

$$u_{(x_i)} = \frac{S}{\sqrt{n}} \dots\dots\dots 3.6$$

Where n is the number of measurements, which is equal to 10.

The expanded measurement uncertainty (confidence interval of 95%), U_e , is calculated as:

$$U_{e\pm 95\%} = \bar{x} \pm t_{0.95, n-1} U_c(E) = 1.96 U_c(E) \dots\dots\dots 3.7$$

where \bar{x} is the mean of the verification checks, $t_{0.95, n-1}$ is the 95th quartile of a t-distribution with n-1 degrees of freedom, and $U_{e\pm 95\%}$ is the 95% confidence range of the mean verification checks.

The hybrid uncertainty is given by

$$\sigma_{\text{hybrid}} = \sqrt{U_e^2 + \sigma_a^2 + \sigma_b^2} \dots\dots\dots 3.8$$

where U_e is the type A uncertainty found through the standard deviation of the mean verification checks, σ_a is the type B uncertainty for the field instrument of interest σ_b is the uncertainty associated with the calibration standards.

A normal probability distribution was assumed for all sources of uncertainty. The electric field intensity was reported as $E \pm \sigma_{\text{hybrid}}$ and was in units of V/m. This reported uncertainty is based on a standard uncertainty multiplied by the coverage factor of 1.96 which yields a 95% level of confidence for the near-normal distribution typical of most measurement results. The uncertainty analysis is based on reference [ECC RECOMMENDATION, 2007)]

3.9 Sample Calculations

3.9.1 Sample calculation of power density

For RBS1 the field strength in dB μ V/m was registered as 71.59 dB μ V/m. The field strength was then converted to standard unit of electric field strength in volts per meter (V/m) using equation 3.1

$$E (V/m) = 10^{\left(\frac{F-120}{20}\right)}$$

$$E (V/m) = 10^{\left(\frac{71.69-120}{20}\right)}$$

$$E (V/m) = 3.84 \text{ mV/m}$$

The results of the electric fields at the respective RBS are presented in appendix B.

The power density levels was then computed using equation 3.2

$$S = \frac{E^2}{377} = 377H^2$$

$$S = \frac{(3.84E - 3)^2}{377}$$

$$S = 0.0391\mu\text{W/m}^2$$

The results of the power density levels at the respective RBS 1 are presented in Appendix B.

3.9.2 Sample calculation of electric spatial average

For RBS 1, the electric spatial average was computed using equation 3.3 and the data from the computed measured electric field levels in Appendix D.

$$E_{\text{spatial_average}} = \sqrt{\frac{\sum_{i=1}^n E_i^2}{n}}$$

From Appendix D Table 3 $\sum E^2$ of RBS 1 inside buildings = 1.68E-3

Where n = 10

$$E_{\text{spatial average}} = \sqrt{\frac{1.68E-3}{10}}$$

$$E_{\text{spatial average}} = \sqrt{1.68E-4}$$

$$E_{\text{spatial average}} = 1.2E-2 \text{ V/m}$$

The results of spatial average electric field are presented in Appendix D.

3.9.3 Sample calculation of Exposure Quotient

For the level of compliance, the ratio $S_{\text{meas}}/S_{\text{icnirp}}$ was calculated for each location as well as facility, where S_{meas} is the value determined from equation 3.3 and S_{icnirp} is the value of existing maximum permissible emission level set by ICNIRP. ICNIRP exposure quotient for both the members of general public and occupational were computed using the stipulated reference power density levels of 4.5W/m² and 22.5W/m² respectively. General public and occupational quotient of RBS1 inside building were computed using the equation 3.3

$$\text{Exposure Quotient} = S_{\text{meas}} / S_{\text{Icnirp}}$$

Where S_{meas} = Calculated power density, S_{Icnirp} = stipulated ICNIRP power density reference level.

$$\text{General public exposure quotient} = \left(\frac{7.47E-9}{4.5} \right) = 1.66E-09$$

$$\text{Occupational exposure quotient} = \left(\frac{7.47E-9}{22.5} \right) = 3.32E-10$$

The results of exposure quotient are presented in Table 5.

3.9.4 Sample calculation of Uncertainty Estimation

The uncertainty estimation of RBS1 inside building was computed as follows:

Firstly, the standard deviation was computed employing equation 3.5

$$S = \sqrt{\frac{\sum_{i=1}^n (x_i - \bar{x})^2}{n-1}}, \text{ where } n \text{ is the number of measurement points.}$$

$$\sum_{i=1}^n (x_i - \bar{x})^2 = 7.57E-4$$

$$S = \sqrt{\frac{7.57E-4}{10-1}}$$

$$S = 9.17E-3$$

Secondly, the standard uncertainty was computed employing equation 3.6 and standard deviation value.

$$u_{(x_i)} = \frac{9.17E-3}{\sqrt{10}}$$

$$u_{(x_i)} = 2.89E-3$$

Thirdly, the combined standard uncertainty, $U_c(E)$ was computed employing equation 3.4.

$$U_c(E) = \sqrt{\sum_{i=1}^n (C_i * u_{(x_i)})^2} \text{ where } C_i \text{ is the sensitivity coefficient. In this case, it is}$$

given as $C_i = 1$.

$$U_c(E) = \sqrt{(1 * 2.89E-3)^2}$$

$$U_c(E) = 2.89E-3$$

Lastly, the expanded measurement uncertainty was then computed employing equation 3.7

$$U_{e\pm 95\%} = \bar{x} \pm t_{0.95, n-1} U_c(E) = 1.96 U_c(E)$$

Therefore

$$U_{e\pm 95\%} = 1.96 \times 2.89E-3$$

$$U_{e\pm 95\%} = 5.66E-3$$

Hence, the expanded measurement uncertainty for RBS1 inside building was 5.66E-3.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Introduction

This chapter gives the results of electric field strength levels measured from vicinity of rooftop base station sites and tower base station sites where the members of the public are likely to be exposed. Twenty (20) rooftop base station sites and twenty (20) tower base station sites were employed for this survey. Spatial average E-field strengths, average power density levels and exposure quotients have been discussed. The found results from this survey were compared to national and international standards.

4.2 The Minimum and maximum electric field levels at the various rooftop base station sites.

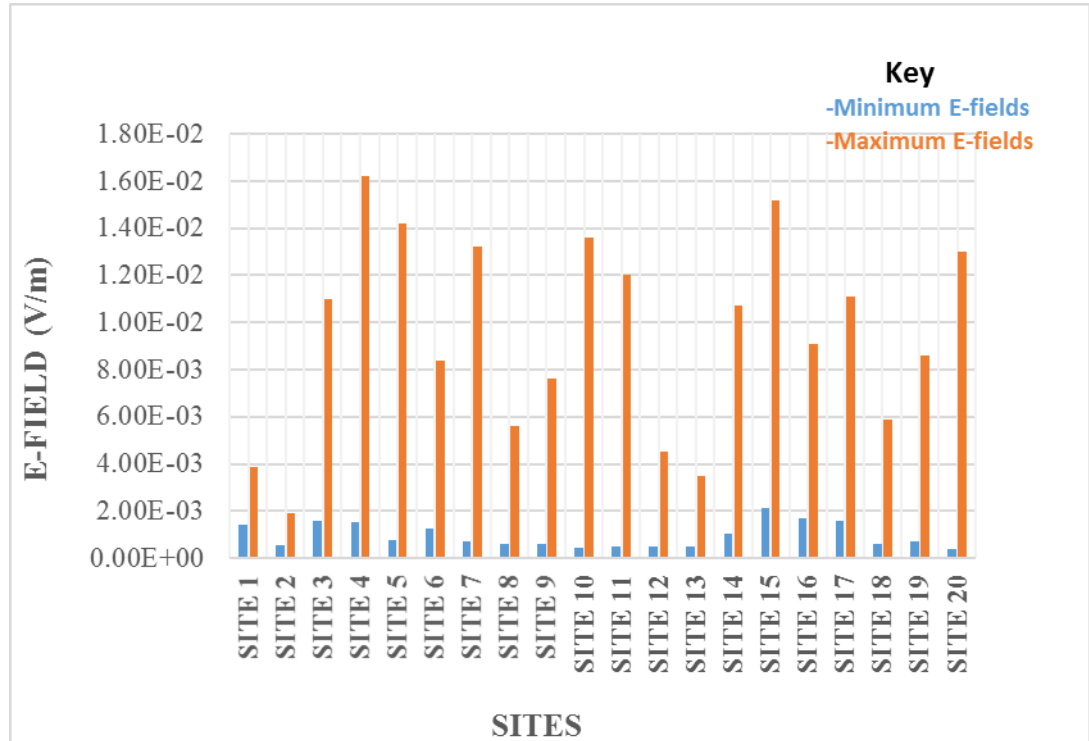


Figure 4.1: A graph of maximum and minimum E-field strengths at the various rooftop sites

Figure 4.1 above shows a plot of maximum and minimum E-field strengths at the various rooftop base station sites. The graph above shows maximum and minimum E-field strengths at the various rooftop sites. The maximum E-field value of 1.62×10^{-2} was recorded at Site 4 followed by 1.52×10^{-2} V/m, 1.42×10^{-2} V/m representing site 15 and 5 respectively. This value could be due to several factor like transmission power, number of radiating antennas at this site. The minimum electric field strength was also measured at site 20 with a value of 3.73×10^{-4} V/m followed by 4.42×10^{-4} V/m, 4.73×10^{-4} V/m representing site 10 and 11 respectively as shown in table 4.1 at appendix D. This minimum value could also be due to the thick concrete walls and concrete ceilings absorbing most of the emissions from the radiating antennas.

4.3 Spatial average electric field strengths inside and outside buildings at the various rooftop sites.

Spatial averages have been found inside and outside buildings for each of the twenty rooftop sites. For inside the buildings, Site 15 had relatively high E-field strength of $6 \times 10^{-3} \pm 3 \times 10^{-3}$ V/m, Site 4 and Site 7 also had values of the order; $6 \times 10^{-3} \pm 4 \times 10^{-3}$ V/m and $5 \times 10^{-3} \pm 4 \times 10^{-4}$ V/m respectively. Some sites had relatively low values of E-field strength within the regions of interest. Outside the buildings, Site 4 registered electric field strength of $10 \times 10^{-3} \pm 4 \times 10^{-3}$ V/m, Site 15 and Site 20 also had values of the order; $9 \times 10^{-3} \pm 4 \times 10^{-3}$ V/m and $8 \times 10^{-3} \pm 2 \times 10^{-3}$ V/m respectively.

The least value inside buildings was recorded at Site 8 with a value of $8 \times 10^{-4} \pm 3 \times 10^{-4}$ V/m whilst that for outside the buildings was registered at Site 2 with $1 \times 10^{-3} \pm 2 \times 10^{-4}$ V/m. The low values of spatial averages of E-field intensities inside buildings could be due to the high attenuation caused by thick concrete walls and ceilings.

The high values outside buildings could also be attributed to factors such as reflection, diffraction and diffusion of the transmitted signal as it hits surfaces of metal structures like container shops and gates.

It could also be due to the transmitted power of the radiating antennas and measurements taken in the far field region with little or no attenuation. The results of spatial averages inside and outside buildings have been presented in Table 4.2 at appendix D.

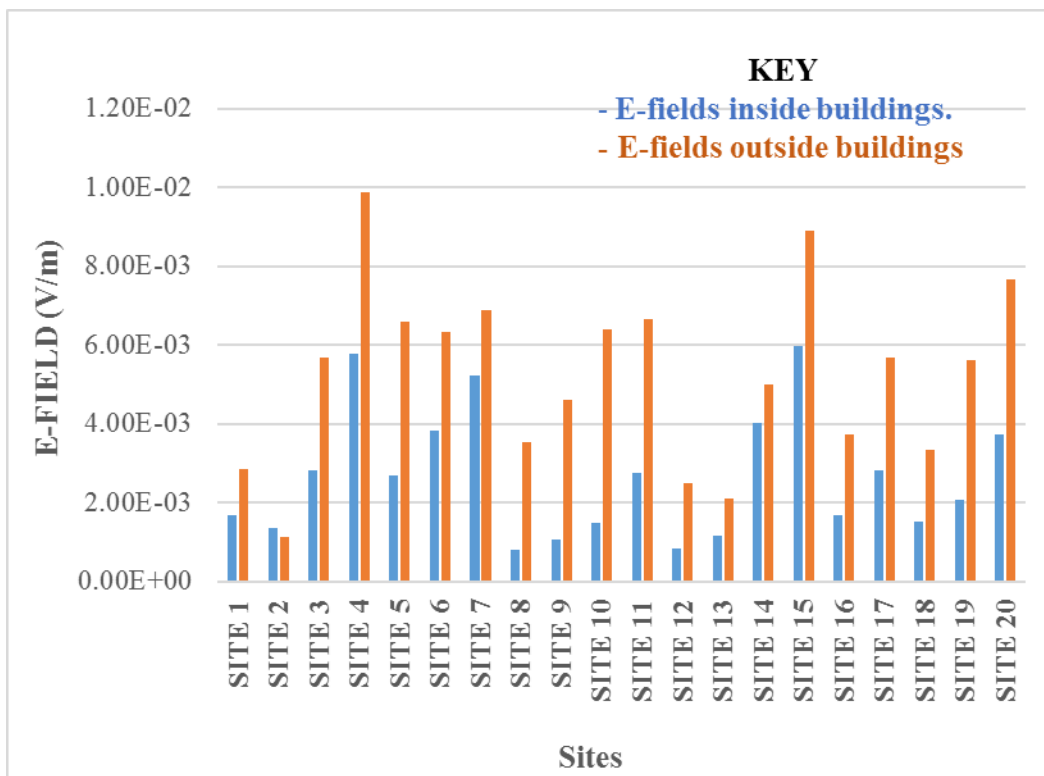


Figure 4.2 show a plot of spatial averages E-field intensities inside and outside buildings at the various rooftop sites.

4.4 Calculated average power density levels inside and outside buildings at the various rooftop sites.

There are several factors that can influence the strength of power density levels measured from radiating antennas of mobile phone base stations. These include the distance from radiating antennas where the intensity decrease according to the inverse square law. Also, power densities fluctuates according to the number calls.

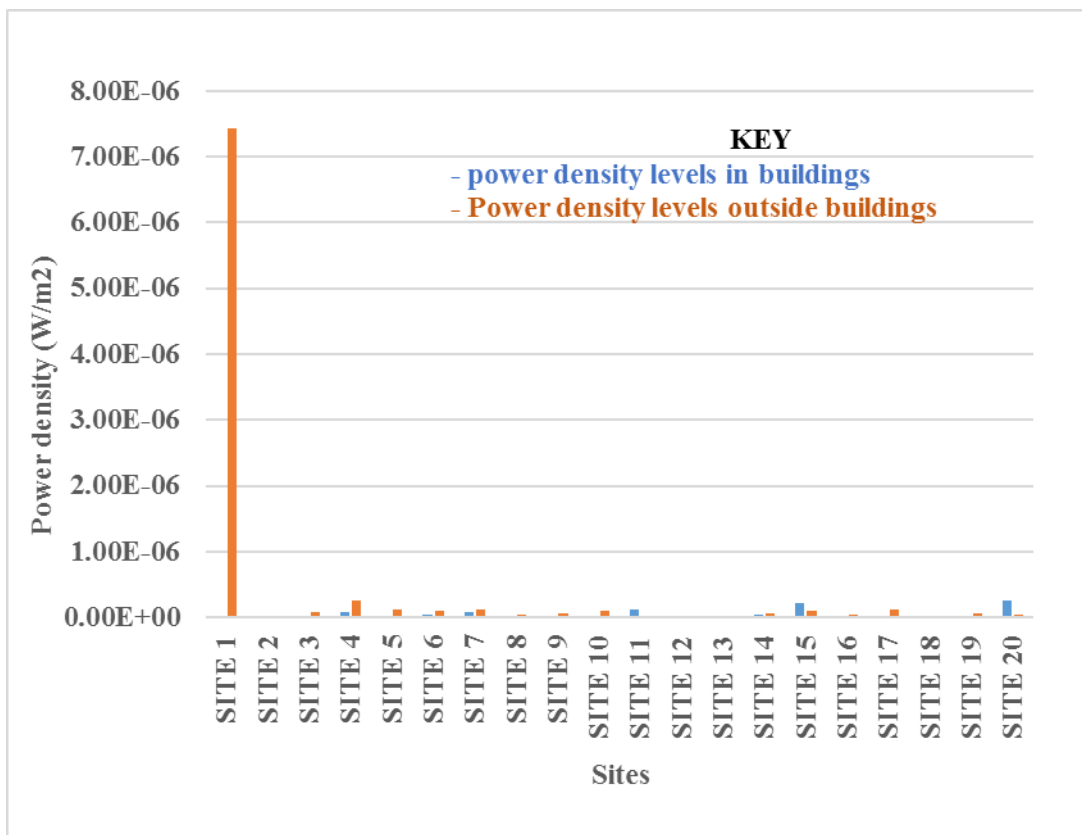


Figure 4.3 shows a plot of average power density levels inside and outside buildings at the various rooftop sites.

From the graph above, Site 1 registered the highest power density located outside building of value $7.440\mu\text{W}/\text{m}^2$ followed $0.259\mu\text{W}/\text{m}^2$ and $0.126\mu\text{W}/\text{m}^2$ representing

Sites 4 and 7 respectively. Considering power densities inside the buildings, site 20 recorded the highest of value $0.246\mu\text{W}/\text{m}^2$ followed by $0.214\mu\text{W}/\text{m}^2$ and $0.117\mu\text{W}/\text{m}^2$ representing sites 15 and 11 respectively.

The low power densities values inside building could be attributed to low E-field levels measured inside buildings. This is can also be due to high attenuation caused by thick concrete walls and ceilings. The high values average power densities outside buildings could be due to reflective structure like metal container shops and gates scattered in the locality of the base station. It could also be attributed to the number of radiating antennas mounted at the sites. It was required that levels of power densities will reduce as measurements were made some distances away from the radiating base station antenna according to the inverse square law. This was not observed in majority of the cases due to variations of signals detected during measurement. The variations could be attributed to factors like reflection, diffraction and diffusion in the locality of the base station. Table 4.3 in appendix D presents average power densities inside and outside buildings at various sites.

4.5 Exposure quotient for the rooftop base station sites.

The exposure quotient is the ratio of the measured power density levels determined in this survey to the limits for maximum permissible exposure levels stipulated by ICNIRP. The recommended maximum value of the exposure quotient should be unity or equal to one (1). A value greater than one connotes that levels to which people may be exposed exceed the reference level. The highest exposure quotient values found in this survey for general public inside and outside buildings are 1.31×10^{-7} and 1.65×10^{-6} at Sites 15 and 1 respectively.

Also, maximum exposure quotient for occupational inside and outside buildings are 2.11×10^{-9} and 3.30×10^{-7} at 15 and 1 respectively which is very small as shown in Table 4.4 at appendix D. In general, value obtained for the exposure quotients are very small compared to the reference level of one (1).

This values could be as a result of the measurements been taken in the far field regions of the radiating antennas at the sites. The main purpose of exposure quotient is to assist in checking for compliance with national and international accepted limits for maximum exposure level. Figure 4.4 shows the pictorial representation of the value discussed above.

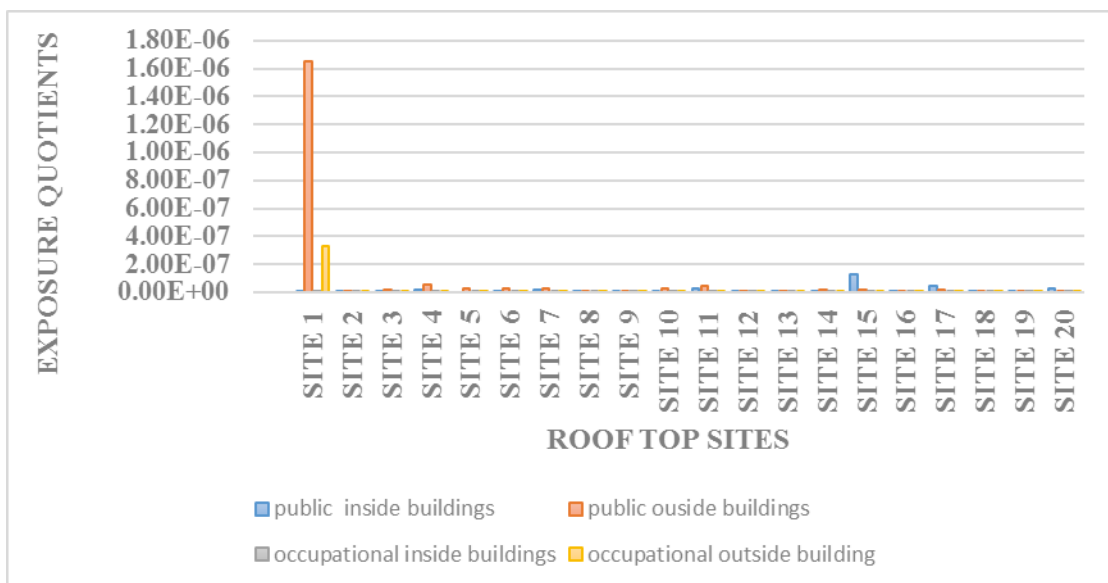


Figure 4.4 depicts a plot of exposure quotients for public and occupational inside and outside buildings at the various rooftop site.

4.6 Comparison of results with national and international standards.

ICNIRP guidelines are the most accepted guidelines for non-ionizing radiation (ICNIRP, 2010). They are endorsed by the World Health Organization (WHO), for the International Union for Telecommunication (ITU) and for more than 30 countries all over the world including administrations of health, telecommunications, environment and others. In Ghana, the relevant regulatory bodies have adopted public and occupational reference levels guidelines set by ICNIRP / ITU-T K.52.

ICNIRP recommends 90V/m as the occupational exposure reference level for E-field strength for RF within the frequency range 400-2000MHz and 41.25V/m as reference level for general public exposure for the same frequency range. The maximum measured electric field strength for inside and outside building are 5.98×10^{-3} V/m at Site 15 and 9.89×10^{-3} V/m. The corresponding power densities for these E-fields are 9.5×10^{-2} W/m² and 2.6×10^{-1} W/m². The 9.5×10^{-2} W/m² represents 2.11E-06% of the ICNIRP limit and 1.58×10^{-6} % for FCC limit at Site 15 inside buildings. 2.59×10^{-1} W/m² also corresponds to 5.76×10^{-6} % for ICNIRP limit and 4.32×10^{-6} % for FCC limit for outside buildings.

These values are by far below the reference levels set for both general public and occupational exposures.

4.7 Results for a typical tower mobile phone base station sites.

Spatial averages have also been obtained for the twenty tower base station sites. Site 14 had comparatively high value of E-field strength of $1.31 \times 10^{-2} \pm 1.02 \times 10^{-3}$ V/m. Sites 6 and 19 also registered E-field strength values of the order $1.09 \times 10^{-2} \pm 5.86 \times 10^{-3}$ V/m and $9.76 \times 10^{-3} \pm 2.57 \times 10^{-3}$ V/m respectively. Some sites recorded relatively low levels of E-field within the regions of concern. Site 7 registered the lowest E-field

value of $2 \times 10^{-3} \pm 9 \times 10^{-4}$ V/m. The fluctuation in the values could be due to mounted antenna height, antenna transmitted power, mounting angles of the antennas etc. Figure 4.5 shows pictorial representation of the values. Table 4.5 depicts the trends of E-fields for the various towers base station sites at appendix D.

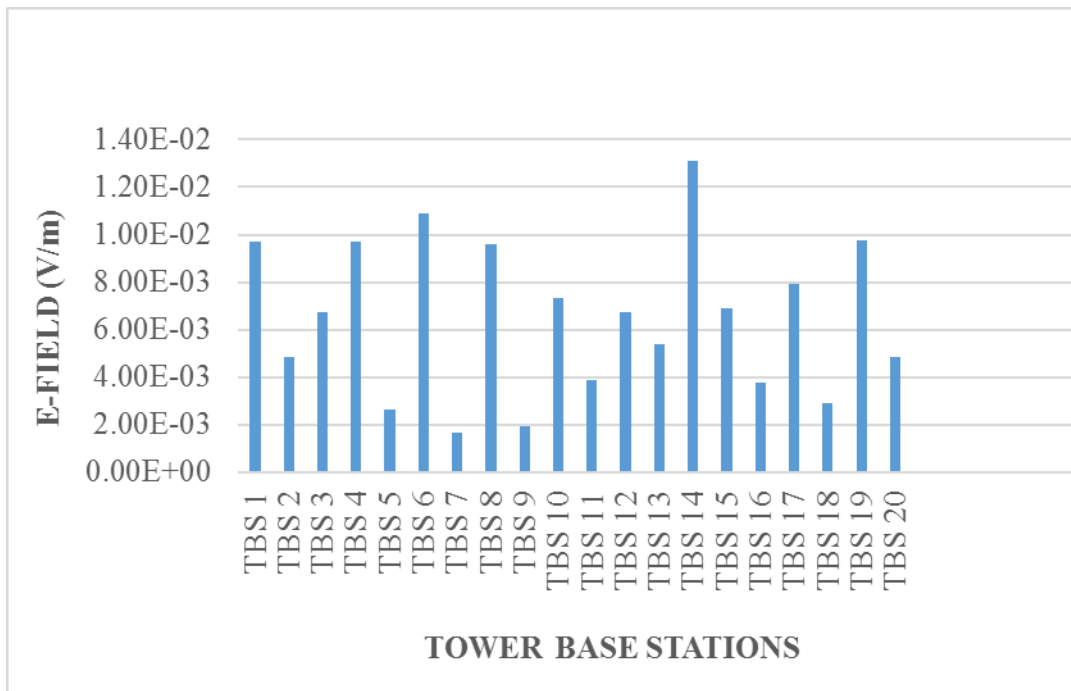


Figure 4.5 shows a plot of spatial average E-fields at the various tower base station sites.

4.8 Comparison of results with other researched works.

The obtained results from this survey was compared to other works done by Azah et al in 2012 in Accra, Ghana, Deatanyah et al in 2011 and Amoako et al in 2009. Azah et al 2012 was done in the immediate vicinity of twenty FM radio stations. The range of power densities reported by Azah et al is between 2.5×10^{-10} to $1.50 \times 10^{-17} \text{ W/m}^2$ at transmission frequency range of 88 to 108 MHz.

For Amoako et al, survey was carried out at public access points in vicinity of fifty cellular phone base station in Accra, Ghana. The found results indicated that power density at public access points varied from as low as 0.01 to as high as 10 $\mu\text{W}/\text{m}^2$ for frequency range of 900MHz. At a transmission frequency of 1800 MHz, the variation of power densities is from 0.01 to 100 $\mu\text{W}/\text{m}^2$. Also Deatanyah et al, 2011 was done at public access in the vicinity of global systems for mobile communication (GSM) cell sites in two major cities in Ghana (Greater and Ashanti Region). The power densities obtained ranged from 0.85 to 1.07 mW/m^2 and from 0.78 to 1.19 mW/m^2 for transmission frequencies of 900 and 1800MHz respectively. The lowest and highest power densities calculated are 0.85 and 0.78 mW/m^2 for 900MHz frequency, all occurring in the Ashanti region. The surveyed results obtained are lower compared to results reported by Deatanyah et al, 2011. It is a bit higher than results of Azah et al, 2011 and Amoako et al, 2009 but show compliance with ICNIRP guidelines.

4.9 Results of exposure quotients and calculated power densities at the various tower base station sites compared to international standard.

Result obtained shows that public exposure quotient values ranged between 1.58E-09 to 1.07E-07 whilst that occupational exposure varied between 3.17E-10 to 2.03E-08. The ICNIRP recommended maximum exposure quotient value of unity or one (1). The variation of power densities also varied between lowest values 0.00713 $\mu\text{W}/\text{m}^2$ at Site 7 to highest value of 0.45700 $\mu\text{W}/\text{m}^2$ at Site 14. ICNIRP recommends reference level of 4.5 and 22.5 W/m^2 for public and occupational respectively, at transmission of frequency 900MHz. Exposure quotient values obtained for the tower sites in this survey were very small because measurements were carried out in the far field regions of the various radiating antenna.

The results obtained shows that the RF emissions from the tower base station sites are within the recommended exposure limits and therefore the estimated power densities are also below the basic restrictions set by ICNIRP. The results as shown in Table 4.6 at appendix D.

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

Real time measurements of E-field strengths from 20 roof top base station sites and 20 tower base station sites have been assessed in Accra, Ghana. Electric field strengths evaluated at the rooftop sites inside buildings ranged from $5.98\text{E-}03 \pm 2.98\text{E-}03$ V/m at Site 15 to $1.12\text{E-}03 \pm 3.21\text{E-}04$ V/m at Site 8. Results for outside buildings also varied from $9.89\text{E-}03 \pm 4.29\text{E-}03$ V/m. Occupational exposure quotient inside buildings varied between $2.11\text{E-}09$ to $1.66\text{E-}11$ whereas that for outside ranged from $3.30\text{E-}07$ to $3.31\text{E-}09$. Public exposure quotient ranged between $1.31\text{E-}07$ and $3.74\text{E-}10$ inside buildings whilst that for outside ranged from $1.65\text{E-}06$ to $7.44\text{E-}10$. At a transmission frequency of 900 MHz, the variation of power densities is from $0.00168\mu\text{W/m}^2$ to $0.24600\mu\text{W/m}^2$ inside buildings and $0.00335\mu\text{W/m}^2$ to $0.744\mu\text{W/m}^2$ to outside buildings.

Results of a typical base station obtained indicated that E-field strengths assessed for the sourced data ranged from $1.31\text{E-}02 \pm 1.02\text{E-}03$ V/m at Site 14 to $1.64\text{E-}03 \pm 9.19\text{E-}04$ V/m at Site 7.

Occupational exposure quotient ranged between $2.03\text{E-}08$ and $3.17\text{E-}10$ whilst that for the general public exposure quotient varied from $1.01\text{E-}07$ to $1.58\text{E-}09$. At a transmission frequency range of 900 MHz, the variation of power densities is from $4.57\text{E-}07$ to $7.13\text{E-}09$ W/m².

This data will serve as a source of information to be considered when setting up standards for policy makers, telecommunication service operators, RF exposed workers and the members of public at large.

The study results obtained from the survey shows that out of the 20 rooftop sites surveyed, the strongest E-field was found in locality of Site 15. Surrounding this cell site or base station are a mosque, business facilities, residential accommodation.

The comparative high value of the E-field could be as a result of many reflective structures like roofing sheets, metal structure scattered in locality in addition to the number antennas compared to others used by many of the sites. This could be due to others like transmission power of the radiating antennas at the site. The results found indicates that the members of the public and occupational exposed workers have comparatively similar exposures. The public received more exposures than the workers in some instances because they reside and work in the locality of the cell site. The results obtained are far below the recommended reference levels set by the agencies like ICNIRP and FCC. However, the result agrees to some extent with other results from similar surveys done by Azah et al 2012, Deatanyah et al 2011 and Amoako et al 2009. Results also contradicts the views or concerns of the general public.

5.2 Recommendations

5.2.1 Recommendation to National Communication Authority (NCA).

The telecommunication service providers should cooperate with the National Communication Authority (NCA) to;

1. Cooperate with research institution like Ghana Atomic Energy Commission (GAEC) and other research scientist to carry out research into possible health effects of RF radiation.
2. Conduct assessment of RF radiation levels within the localities of the base station and also evaluate the impact of the RF radiations on the general public.

- 3 Cooperate with GAEC to carry out radiation safety education for the general public, workers and the management of telecommunication service providers (TSP).
- 4 Set up periodic briefings to telecommunication service providers to notify them of development in the non-ionizing field.
- 5 Cooperate with RPI in its effort of providing financial assistance for research in the field of non-ionizing radiation.

5.2.2 Recommendation to Radiation Protection Institute (RPI) of GAEC

1. RPI should educate the members of the public and occupational exposed workers on RF radiation safety.
2. RPI should ensure that all TSP engage the services of security personnel to prevent unauthorized access to their cell sites or base stations.
3. RPI should cooperate with NCA to formulate guidelines for the installation of antennas on roof top and tower base stations.
- 4 Cooperate orate with Radiation Protection Institute in its effort of conduction research into the possible health effects of RF radiations

5.2.3 Management of Telecommunication Service Providers (TSP).

1. They should establish department of RF radiation safety and engage the services of Radiation Protection Officers (RPOs) charge with duty of ensuring RF safety of the workers.
2. They should cooperate with RPI to provide training and education to workers on radiation safety issues.
3. They should ensure that the required transmission power is supply to antennas to Prevent very high RF exposures to the vicinities of the installation facilities.

5.2.4 Occupationally Exposed Workers

1 RF exposed workers should ensure at all times that RF systems and antennas are turn off before starting maintenance work.

2 They should make sure to spend less period of time in RF exposure environment RF systems and antennas are in operation to prevent undue exposure.

3 They should also ensure to honor their annual level period to stay away from RF exposed environment for some time.

5.2.5 Recommendation to the members of the Public.

1. The general public should not build story buildings very close to roof top base stations to avoid undue exposure to RF radiations.

2. They should not lease pieces of land within densely populated areas to be used as base station sites for transmitting RF radiations.

5.2.6 Recommendation for Further Studies

1. RF assessment should be conducted on all the other rooftop and tower base station antennas nation-wide to properly evaluate RF exposure in the locality to the general public.

2. RF exposure assessment using either the ICNIRP or IEEE predictive model.

REFERENCES

- Amoako, J. K., Fletcher, J. J., & Darko, E. O. (2009). Measurement and analysis of radiofrequency radiations from some mobile phone base stations in Ghana. Retrieved from <http://rpd.oxfordjournals.org/content/135/4/256/F1.expansional>
- Azah, K.C., Amoako, J. K., & Fletcher, J. J. (2011). Assessment of the levels of radiofrequency fields in the vicinity of FM radio stations in Accra, Ghana. Retrieved from <http://rpd.oxfordjournals.org>
- Cember, H., & Johnson, T. E. (2009). *Introduction to health physics (4th ed.)*. McGraw Hill Companies, Inc. USA pg. 721.
- Cooper, T. G., Mann, S. M., Blackwell, R. P., & Allen, S.G. (2007). Occupational Exposures to Electromagnetic fields at Radio Transmitter sites. HPA -RPD-026<http://www.inictel.gob.pe/dit/radiaciones>
- Critical Review Biomedical Engineering (2003). Critical Review Biomedical Engineering. Health risks of electromagnetic fields, *31*(311).
- Cruz, V. (2005). NIR Measurements; Principles and Practices of EMF characterization and measurements, National Institute for Research and Training in Telecommunications- Peruvian National University of Engineering (INICTEL- UNI) RC-11.
- Dahme, M. (1999). Residential RF exposure to radiation protection dosimetry. *83*:113-117
- Deatanyah P., Amoako J., K, Fletcher J., J, Adjei D., N, Dwapanyin, G. O, & Amoatey E. (2012) Assessment of radiofrequency radiation within the vicinity of some GSM base stations in Ghana. *Radiation protection Dosimetry*, *135*(4), 256-260
- Expert group on health effects of electromagnetic fields (2005). Health Effects of Electromagnetic fields, Department of Communication Marine and Natural Resources.
- FCC (1997). Evaluating Compliance with FCC Guidelines for Human Exposure to Radiofrequency Electromagnetic Fields. Supplement B Edition 01-01 to OET Bulletin 65. Edition 97-01.
- FCC (2001). Evaluating Compliance with FCC Guidelines for Human Exposure to Radiofrequency Electromagnetic Fields Supplement C Edition 01-01 to OET Bulletin 65. Edition 97-01.

- ICNIRP (1998). Guidelines for limiting exposure to time varying electric, magnetic and electromagnetic fields. (Up to 300 GHz). *Health Physics* 74(4):494-522
- ICNIRP (2009). Exposure to high frequency electromagnetic fields, biological effects and health consequences (100 kHz - 300GHz). *Health Physics*, 74,494 – 522
- IEEE Committee on Man and Radiation (2002). Medical aspect of radiofrequency radiation over exposure. *Health Physics*, 82, 387-391.
- Limits of Human Exposure to Radiofrequency electromagnetic fields in the frequency range from 3 kHz to 300 GHz. Safety code 6. Environmental Health Directorate, Health Protection Branch. Published by authority of the Ministry of Health. Health Canada, 2009.
- International Commission on Non-ionizing Radiation Protection on the guidelines for limiting exposure to time varying electric and magnetic fields (1Hz –100Hz) published in *health physics* 99(6): 818-836; 2010. Fact Sheet LF November LF 2010.
- ICNIRP (2010). Fact Sheet on the guidelines for limiting exposure to time varying Electric and magnetic fields (1Hz – 100 kHz).Published in *health physics* 99(6):818-836; Factsheet LF November, 2010.
- International Telecommunications Union, Guidance to measurement and numerical prediction of electromagnetic fields for compliance with human exposure limits for telecommunication installations, Series K: Protection against Interference, Recommendation K.61 (2003),
- Ismail, A.F., Sidek, N.I., Abdullah, K., & Hashim, W. (2013). Predicting radio frequency radiation from mobile communication base station. *International Journal of Computer and Communication Engineering Vol.2 No. 4*
- ITU (2004). Guidance on complying with limits for human exposures to electromagnetic fields. Series K: Protection against interference ITU-T recommendation K.52
- IARC (2011). International Association on Research for Cancer (IARC) classifies radiofrequency Electromagnetic fields as possibly carcinogenic to human. Press release No. 208.
- Jose (2009). Exposure of workers to electromagnetic fields of open questions on exposure assessment techniques, *15* (1), 3-33.

- Man Ah K., & Shahidan R. (2005). Assessment of radiofrequency/microwave radiation emitted by antennas of rooftop mounted mobile phone base stations. *Vol. 121* No. 2 pp 122 – 127. Retrieved from <http://rpd.oxfordjournals.org>
- Measuring Non-ionizing electromagnetic radiation (9 kHz – 300 GHz)
 Recommendation adopted by the working group “Frequency Management” (FM). Electromagnetic Communications Committee (ECC) with the European Conference of Postal and Telecommunication Administration (CEPT). Edition of 30 September, 2002.
- MMF (2008). Mobile phone base stations EMF/health fact pack. Mobile manufacturer forum. Diamart building, 80, Boulevard A. Reyers B-130 Brussels, Belgium November, 2008.
- Non-ionizing Radiation – Source, biological effects, Emissions and Exposure. Proceedings of the International Conference on Non-ionizing Radiation at UNITEN. Electromagnetic fields and our Health. 20th–22nd October, 2003.
- Schüz. J., & Mann, S. (2000). A discussion of potential exposure metrics for use in epidemiological studies on human exposure to radio waves from mobile phone base stations.
- Steve, W. (2001). Newnes Telecommunication Pocket Book by Steve Winder (3rd ed.), pg.139
- WHO (1998). Electromagnetic fields and public health: Extremely low frequency fields Fact Sheet No. 183.
- WHO (2006). WHO fact sheet “Electromagnetic fields and public health” fact sheet No. 304, May, 2006.
- World English Dictionary (2008). Microsoft student 2008[DVD]. Redmond, WA: Microsoft Corporation, 2008

APPENDICES

APPENDIX A (Reference levels for public and occupational exposures)

Table A1 Typical sources of electromagnetic fields (Miller, 2002)

Frequency range	Frequencies	Some examples of exposure sources
Static	0 Hz	VDU (video displays); MRI and other diagnostic /scientific instrumentation; Industrial electrolysis;
ELF	0-300 Hz	Power lines; Domestic distribution lines, Domestic appliances; Electric engines in cars, train; Welding devices
IF	300 Hz – 3 kHz	VDU; anti theft devices in shops, hands free access control systems, card readers and metal detectors; MRI; Welding devices
RF	kHz– 300 GHz	Mobile telephony; Broadcasting and TV; Microwave oven; Radar, portable and stationary radio transceivers, personal mobile radio; MRI

Table A2 ICNIRP reference levels for occupational exposure (unperturbed rms values) (ICNIRP, 1998)

Frequency range	E-field strength (Vm ⁻¹)	H-field strength (Am ⁻¹)	B-field (μT)	Equivalent plane wave power density S _{eq} (Wm ⁻²)
1Hz	-	1.63 x 10 ⁵	2 x 10 ⁵	-
1-8Hz	20 000	1.63 x 10 ⁵ /f ²	2 x 10 ⁵ /f ²	-
8-25Hz	20 000	2 x 10 ⁴ /f	2.5 x 10 ⁴ /f	-
0.025-0.82kHz	500/f	20/f	25/f	-
0.82-65kHz	610	24.4	30.7	-
0.065-1MHz	610	1.6/f	2/f	-
1-10MHz	610/f	1.6/f	2/f	-
10-400MHZ	61	0.16	0.2	10
400-2000MHz	3/f ^{0.5}	0.008/f ^{0.5}	0.01/f ^{0.5}	f/40
2-300GHz	137	0.36	0.45	50

***NOTE**

1. f as indicated in the frequency range column
2. Provided that the basic restrictions are met and adverse indirect effect can be excluded, field strength can be excluded.
3. For frequencies between 100kHz and 10GHz, S_{eq} , E^2 , H^2 and B^2 are to be averaged over any 6 minute period
4. For peak values at frequencies up to 100kHz see note 3 above
5. For frequencies between 100kHz and 10GHz, S_{eq} , E^2 , H^2 and B^2 are to be averaged over any $68/f^{1.05}$ minute period (f in GHz)
6. No E-field values is provided for frequencies < 1 Hz which are effectively static electric fields. Electric shocks from low impedance sources is prevented by established electrical safety procedures for such equipment.

Table A3 ICNIRP reference levels for general public exposure from the main telecommunications services and systems (WHO)

Services	Frequency range (MHz)	E-field strength (Vm^{-1})	H-field strength (Am^{-1})	B-field (μT)	Equivalent plane wave power density S_{eq} (Wm^{-2})
FM broadcast	88-108	28.0	0.073	0.092	2.0
VHF TV	54-88 174-216	28.0	0.073	0.092	2.0
UHF TV	407-806	29.8	0.08	0.099	2.0
800MHz	806-869	40.0	0.10	0.13	4.3
Mobile Telephony 800MHz	824-894	40.6	0.11	0.14	4.4
Mobile Telephony 800MHz	890-960	41.0	0.11	0.14	4.5
PCS 1800	1710-1880	56.9	0.15	0.19	8.6
PCS 1900	1850-1900	60.5	0.16	0.20	9.7

Table A4 Maximum permissible exposures for people in controlled environment (IEEE, 2006)

Frequency range (MHz)	RMS electric field strength[E] ^a (V/m)	RMS magnetic field strength[H] ^a (A/m)	RMS power density(S), E-field, H-field (W/m)	Averaging time [E] ² , [H] ² or S (min)
0.1-1.0	1842	16.3/ f_M	(9000,100000/ f_M^2) ^b	6
1.0-30	1842/ f_M	16.3/ f_M	(9000/ f_M^2 ,100000/ f_M^2)	6
30-100	61.4	16.3/ f_M	(10, 100000/ f_M^2)	6
100-300	61.4	0.163	10	6
300-3000	-	-	$F_{M/20}$	6
3000-30000	-	-	100	19.63/ $f_G^{1.079}$
30000-300000	-	-	100	2.524/ $f_G^{0.476}$

***NOTE**

1. f_M is the frequency in MHz,
2. f_G is the frequency GHz
3. ^aFor exposures that are uniform over the dimensions of the body, such as certain far-field plane waves exposures the exposure field strengths and power densities are compared with MPE in the Table. For non-uniform exposures, the mean values of the exposure fields as obtained by spatially averaging the squares of the field strengths or averaging the power densities over an area equivalent to the vertical cross section of the human body(projected area), or a smaller area depending on the frequency, area compared with MPEs in the Table.
4. ^bThese plane-wave equivalent power density values are commonly used as a convenient comparison with MPE at higher frequencies and are displayed on some instruments.

Table A5 FCC Limits for Maximum Permissible Exposure (MPE) for Occupational/Controlled Exposure (FCC, 1997)

Frequency Strength (E) (MHz)	Electric Field Strength (H) (V/m)	Magnetic Field (S) (mW/cm ²) (A/m)	Power Density E ² , H ² or S	Averaging Time (minutes)	Range
0.3-3.0	614	1.63	(100)*	6	
3.0-30	1842/f	4.89/f	(900/ f_2)*	6	
30-300	61.4	0.163	1.0	6	
300-1500	--	--	f/300	6	
1500-100,000	--	--	5	6	

NOTE

1. f = frequency in MHz
2. *Plane-wave equivalent power density
3. Occupational/controlled limits apply in situations in which persons are exposed as a consequence of their employment provided those persons are fully aware of the potential for exposure and can exercise control over their exposure.
4. Limits for occupational/controlled exposure also apply in situations when an individual is transient through a location where occupational/controlled limits apply provided he or she is made aware of the potential for exposure.

Table A6 Action level (maximum permissible exposure for the general public when an RF safety program is available) (IEEE, 2006).

Frequency range (MHz)	RMS electric field strength [E] ^a (V/m)	RMS power density(S), E-field, H-field (W/m)	Averaging time [E] ² , [H] ² or S (min)	
0.1-1.34	614	(1000, 100000/ f_M^2) ^c	6	6
1.34-3	$823.8/f_M$	(1800/ f_M^2 , 100000/ f_M^2)	$f_M^{2/0.3}$	6
3-30	$823.8/f_M$	(1800/ f_M^2 , 100000/ f_M^2)	$f_M^{2/0.3}$	6
30-100	27.5	(2, 9400 000/ $f_M^{3.336}$)	30	6
100-400	27.5	2	30	6
400-2000	-	$f_M/200$	30	
2000-5000	-	10	30	
5000-30 000		10	150/ f_G	
30 000-100 000	-	10	5048/ $f_G^{0.476}$	
100000-300 000	-	(90 f_G -7000)/200	5048/[(9 f_G -7000)/ $f_G^{0.476}$]	

***NOTE**

1. f_M is the frequency in MHz,
2. f_G is the frequency GHz
3. ^aFor exposures that are uniform over the dimensions of the body, such as certain far-field plane waves exposures the exposure field strengths and power densities are compared with MPE in the Table. For non-uniform exposures, the mean values of the exposure fields as obtained by spatially averaging the squares of the field strengths or averaging the power densities over an area equivalent to the vertical cross section of the human body(projected area), or a smaller area depending on the frequency, area compared with MPEs in the Table.
4. ^bThe left column is the averaging time for [E]², the right column is the averaging time for [H]². For frequencies greater than 400MHz, the averaging time is for power density
5. ^cThese plane-wave equivalent power density values are commonly used as a convenient comparison with MPE at higher frequencies and are displayed on some instruments

Table A7 Maximum permissible exposure action levels from the main telecommunication

Service	Frequency range (MHz)	E _{rms} (V/m)	S _{rms}		Averaging time [E] ² , [H] ² or S (min)	
			E field,	H field		
VHF TV	54-88	27.50	2.00	6.27	30	6
FM broadcast	88-108	27.50	2.00	2.14	30	6
VHF TV	174-216	27.50	2.00	2.00	30	6
Trunking 800MHz	806-869	-	4.19		30	
Mobile Telephony 800MHz	824-894	-	4.30		30	
Mobile Telephony 900MHz	890-960	-	4.63		30	
PCS 1800MHz	1710-1880	-	8.98		30	
PCS 1900MHz	1850-1900	-	9.38		30	

Table A8: FCC Limits for Maximum Permissible Exposure (MPE) for General Population/Uncontrolled Exposure (FCC, 1997)

Frequency Range (MHz)	Electric Field Strength (E) (V/m)	Magnetic Field Strength (H) (A/m)	Power Density (S) (mW/cm ²)	Averaging Time E ² , H ² or S (minutes)
0.3-1.34	614	1.63	(100)*	30
1.34-30	824/f	2.19/f	(180/f ₂)*	30
30-300	27.5	0.073	0.2	30
300-1500	--	--	f/1500	30
1500-100,000	--	--	1.0	30

NOTE

1. f is frequency in MHz
2. *Plane-wave equivalent power density

APPENDIX B (Electric field levels at each rooftop base station)

Table B1: Measured electric fields at 10 locations at RBS 1

Location	Geographic co-ordinates [GPS]	Electric field $E/\pm 4.68E-04V/m$
A	N 05° 40.162' W000° 14. 411'	2.44E-03
B	N 05° 40.163' W000° 14. 413'	3.84E-03
C	N 05° 40.167' W000° 14. 412'	2.52E-03
D	N 05° 40.163' W000° 14. 407'	2.05E-03
E	N 05° 40.163' W000° 14. 412'	1.75E-03
F	N 05° 40.166' W000° 14. 395'	1.42E-03
G	N 05° 40.170' W000° 14. 429'	1.41E-03
H	N 05° 40.168' W000° 14. 407'	2.54E-03
I	N 05° 40.145' W000° 14. 421'	2.32E-03
J	N 05° 40.167' W000° 14. 430'	3.16E-03

Table B2: Measured electric fields at 10 locations at RBS 2

Location	Geographic co-ordinates [GPS]	Electric field $E/\pm 2.53E-04Vm^{-1}$
A	N 05° 39.984' W000° 14. 346'	1.43E-03
B	N 05° 39.985' W000° 14. 334'	1.20E-03
C	N 05° 39.989' W000° 14. 327'	7.82E-04
D	N 05° 39.993' W000° 14. 340'	1.57E-03
E	N 05° 39.989' W000° 14. 333'	1.92E-03
F	N 05° 39.989' W000° 14. 329'	8.15E-04
G	N 05° 39.994' W000° 14. 336'	5.68E-04
H	N 05° 39.988' W000° 14. 335'	1.33E-03
I	N 05° 40.003' W000° 14. 341'	1.04E-03
J	N 05° 40.013' W000° 14. 332'	4.11E-04

Table B3: Measured electric fields at 10 locations at RBS 3

Location	Geographic coordinates [GPS]	Electric field $E/\pm 1.85E-03V\text{m}^{-1}$
A	N 05° 34.999' W000° 12. 988'	6.61E-03
B	N 05° 35.002' W000° 12. 993'	1.10E-02
C	N 05° 34.997' W000° 12. 991'	1.59E-03
D	N 05° 35.008' W000° 12. 991'	4.27E-03
E	N 05° 35.003' W000° 12. 992'	1.72E-03
F	N 05° 35.003' W000° 12. 984'	7.86E-04
G	N 05° 35.011' W000° 12. 999'	4.11E-03
H	N 05° 34.984' W000° 12. 994'	4.89E-03
I	N 05° 34.984' W000° 12. 973'	3.82E-03
J	N 05° 34.992' W000° 12. 955'	2.34E-03

Table B4: Measured electric fields at 10 locations at RBS 4

Location	Geographic co-ordinates [GPS]	Electric field $E/\pm 3.23E-03V\text{m}^{-1}$
A	N 05° 34.627' W000° 12. 517'	1.01E-02
B	N 05° 34.628' W000° 12. 518'	2.37E-03
C	N 05° 34.629' W000° 12. 518'	1.62E-02
D	N 05° 34.635' W000° 12. 5000'	3.83E-03
E	N 05° 34.629' W000° 12. 512'	2.62E-03
F	N 05° 34.627' W000° 12. 516'	8.87E-03
G	N 05° 34.625' W000° 12. 513'	8.17E-03
H	N 05° 34.628' W000° 12. 520'	3.19E-03
I	N 05° 34.625' W000° 12. 526'	1.51E-02
J	N 05° 34.632' W000° 12. 539'	3.01E-03

Table B5: Measured electric fields at different locations at RBS 5

Location	Geographic co-ordinates [GPS]	Electric field $E/\pm 2.37E-03V\text{m}^{-1}$
A	N 05° 33.468' W000° 12. 836'	1.42E-02
B	N 05° 33.472' W000° 12. 835'	4.76E-03
C	N 05° 33.461' W000° 12. 829'	2.15E-03
D	N 05° 33.459' W000° 12. 828'	2.70E-03
E	N 05° 33.469' W000° 12. 837'	2.53E-03
F	N 05° 33.464' W000° 12. 848'	4.43E-03
G	N 05° 33.460' W000° 12. 841'	4.53E-03
H	N 05° 33.470' W000° 12. 863'	7.70E-04
I	N 05° 33.475' W000° 12. 859'	1.51E-03
J	N 05° 33.472' W000° 12. 856'	2.17E-03

Table B6: Measured electric fields at different locations at RBS 6

Location	Geographic co-ordinates [GPS]	Electric field $E/\pm 2.14E-03V\text{m}^{-1}$
A	N 05° 34.295' W000° 12. 944'	5.33E-03
B	N 05° 34.297' W000° 12. 489'	3.22E-03
C	N 05° 34.303' W000° 12. 493'	2.28E-03
D	N 05° 34.314' W000° 12. 496'	3.75E-03
E	N 05° 34.309' W000° 12. 497'	5.15E-03
F	N 05° 34.309' W000° 12. 482'	8.38E-03
G	N 05° 34.325' W000° 12. 492'	1.26E-02
H	N 05° 34.317' W000° 12. 485'	1.68E-03
I	N 05° 34.299' W000° 12. 487'	1.58E-03
J	N 05° 34.288' W000° 12. 493'	2.55E-03

Table B7: Measured electric fields at 10 locations at RBS 7

Location	Geographic co-ordinates [GPS]	Electric field $E/\pm 2.51E-03V\text{m}^{-1}$ 1
A	N 05° 33.791' W000° 12. 761'	1.21E-03
B	N 05° 33.796' W000° 12. 759'	6.45E-03
C	N 05° 33.793' W000° 12. 757'	6.97E-04
D	N 05° 33.772' W000° 12. 772'	3.16E-03
E	N 05° 33.791' W000° 12. 783'	9.67E-03
F	N 05° 33.790' W000° 12. 764'	2.38E-03
G	N 05° 33.788' W000° 12. 754'	5.30E-03
H	N 05° 33.804' W000° 12. 769'	1.32E-02
I	N 05° 33.808' W000° 12. 755'	6.07E-03
J	N 05° 33.794' W000° 12. 760'	1.64E-03

Table B8: Measured electric fields at 10 locations at RBS 8

Location	Geographic co-ordinates [GPS]	Electric field $E/\pm 1.14E-03V\text{m}^{-1}$ 1
A	N 05° 40.078' W000° 10. 016'	2.10E-03
B	N 05° 40.081' W000° 10. 019'	3.50E-03
C	N 05° 40.081' W000° 10. 019'	1.09E-03
D	N 05° 40.074' W000° 10. 016'	5.86E-04
E	N 05° 40.075' W000° 10. 012'	6.09E-04
F	N 05° 40.080' W000° 10. 016'	2.15E-03
G	N 05° 40.081' W000° 10. 019'	7.83E-04
H	N 05° 40.065' W000° 10. 019'	5.62E-03
I	N 05° 40.067' W000° 09. 999'	5.19E-03
J	N 05° 40.075' W000° 10. 003'	2.63E-03

Table B9: Measured electric fields at 10 locations at RBS 9

Location	Geographic co-ordinates [GPS]	Electric field $E/\pm 1.39E-03V\text{m}^{-1}$
A	N 05° 40.249' W000° 09. 900'	1.42E-03
B	N 05° 40.256' W000° 09. 900'	6.07E-04
C	N 05° 40.253' W000° 09. 913'	1.13E-03
D	N 05° 40.252' W000° 09. 914'	7.72E-04
E	N 05° 40.255' W000° 09. 918'	1.01E-03
F	N 05° 40.258' W000° 09. 919'	3.98E-03
G	N 05° 40.249' W000° 09. 914'	4.30E-03
H	N 05° 40.252' W000° 09. 908'	3.98E-03
I	N 05° 40.254' W000° 09. 895'	4.30E-03
J	N 05° 40.254' W000° 09. 894'	7.60E-03

Table B10: Measured electric fields at 10 locations at RBS 10

Location	Geographic co-ordinates [GPS]	Electric field $E/\pm 2.33E-04V\text{m}^{-1}$
A	N 05° 40.123' W000° 11. 347'	2.75E-03
B	N 05° 40.124' W000° 11. 346'	3.91E-03
C	N 05° 40.130' W000° 11. 346'	2.10E-03
D	N 05° 40.125' W000° 11. 347'	1.88E-03
E	N 05° 40.126' W000° 11. 348'	4.42E-04
F	N 05° 40.122' W000° 11. 350'	7.52E-04
G	N 05° 40.120' W000° 11. 350'	2.60E-03
H	N 05° 40.125' W000° 11. 353'	2.80E-03
I	N 05° 40.142' W000° 11. 360'	4.63E-03
J	N 05° 40.136' W000° 11. 337'	1.36E-02

Table B11: Measured electric fields at 10 locations at RBS 11

Location	Geographic co-ordinates [GPS]	Electric field $E/\pm 2.29E-03V\text{m}^{-1}$
A	N 05° 38.824' W000° 11. 132'	1.20E-02
B	N 05° 38.821' W000° 11. 153'	8.45E-03
C	N 05° 38.818' W000° 11. 135'	4.55E-03
D	N 05° 38.816' W000° 11. 151'	4.90E-03
E	N 05° 38.819' W000° 11. 136'	2.15E-03
F	N 05° 38.812' W000° 11. 140'	4.73E-04
G	N 05° 38.813' W000° 11. 141'	5.77E-04
H	N 05° 38.810' W000° 11. 128'	5.28E-04
I	N 05° 38.829' W000° 11. 124'	4.15E-03
J	N 05° 38.831' W000° 11. 141'	3.49E-03

Table B12: Measured electric fields at 10 locations at RBS 12

Location	Geographic co-ordinates [GPS]	Electric field $E/\pm 8.06E-04V\text{m}^{-1}$
A	N 05° 39.171' W000° 11. 281'	1.54E-03
B	N 05° 39.164' W000° 11. 281'	8.75E-04
C	N 05° 39.161' W000° 11. 288'	2.54E-03
D	N 05° 39.163' W000° 11. 281'	1.29E-03
E	N 05° 39.170' W000° 11. 288'	4.86E-04
F	N 05° 39.176' W000° 11. 286'	4.96E-04
G	N 05° 39.174' W000° 11. 279'	4.50E-03
H	N 05° 39.184' W000° 11. 289'	7.33E-04
I	N 05° 39.152' W000° 11. 287'	1.84E-03
J	N 05° 39.152' W000° 11. 257'	3.11E-03

Table B13: Measured electric fields at 10 locations at RBS 13

Location	Geographic co-ordinates [GPS]	Electric field $E/\pm 5.41E-04V\text{m}^{-1}$
A	N 05° 37.120' W000° 13. 822'	1.26E-03
B	N 05° 37.118' W000° 13. 823'	3.46E-03
C	N 05° 37.117' W000° 13. 819'	2.62E-03
D	N 05° 37.123' W000° 13. 817'	1.92E-03
E	N 05° 37.123' W000° 13. 823'	4.91E-04
F	N 05° 37.120' W000° 13. 818'	6.98E-04
G	N 05° 37.125' W000° 13. 818'	1.50E-03
H	N 05° 37.126' W000° 13. 812'	2.12E-03
I	N 05° 37.115' W000° 13. 810'	1.95E-03
J	N 05° 37.120' W000° 13. 816'	1.67E-03

Table B14: Measured electric fields at 10 locations at RBS 14

Location	Geographic co-ordinates [GPS]	Electric field $E/\pm 1.74E-03V\text{m}^{-1}$
A	N 05° 35.602' W000° 11. 395'	1.86E-03
B	N 05° 35.605' W000° 11. 397'	1.62E-03
C	N 05° 35.608' W000° 11. 397'	3.94E-03
D	N 05° 35.602' W000° 11. 398'	3.59E-03
E	N 05° 35.605' W000° 11. 400'	3.53E-03
F	N 05° 35.604 W000° 11. 404'	3.45E-03
G	N 05° 35.601' W000° 11. 401'	5.30E-03
H	N 05° 35.603' W000° 11. 357'	1.05E-03
I	N 05° 35.614' W000° 11. 398'	1.07E-02
J	N 05° 35.605' W000° 11. 389'	1.55E-03

Table B15: Measured electric fields at 10 locations at RBS 15

Location	Geographic co-ordinates [GPS]	Electric field $E/\pm 2.39E-03V\text{m}^{-1}$
A	N 05° 35.653' W000° 11. 610'	7.55E-03
B	N 05° 35.650' W000° 11. 609'	6.49E-03
C	N 05° 35.653' W000° 11. 612'	1.52E-02
D	N 05° 35.651' W000° 11. 612'	8.06E-03
E	N 05° 35.653' W000° 11. 614'	8.52E-03
F	N 05° 35.65' W000° 11. 614'	4.06E-03
G	N 05° 35.654' W000° 11. 615'	3.25E-03
H	N 05° 35.651' W000° 11. 611'	2.12E-03
I	N 05° 35.643' W000° 11. 604'	1.03E-02
J	N 05° 35.645' W000° 11. 625'	4.70E-03

Table B16: Measured electric fields at 10 locations at RBS 16

Location	Geographic co-ordinates [GPS]	Electric field $E/\pm 9.29E-04V\text{m}^{-1}$
A	N 05° 35.879 W000° 11. 871'	4.87E-03
B	N 05° 35.880' W000° 11. 876'	4.13E-03
C	N 05° 35.877' W000° 11. 877'	4.40E-03
D	N 05° 35.875' W000° 11. 874'	4.09E-03
E	N 05° 35.873' W000° 11. 879'	4.88E-03
F	N 05° 35.869' W000° 11. 877'	1.93E-03
G	N 05° 35.873' W000° 11. 871'	9.07E-04
H	N 05° 35.871' W000° 11. 871'	2.19E-03
I	N 05° 35.883' W000° 11. 867'	1.71E-03
J	N 05° 35.858' W000° 11. 896'	1.96E-03

Table B17: Measured electric fields at 10 locations at RBS 17

Location	Geographic co-ordinates [GPS]	Electric field $E/\pm 2.85E-03V\text{m}^{-1}$
A	N 05° 35.607 W000° 12. 213'	7.61E-03
B	N 05° 35.606' W000° 12. 212'	2.10E-02
C	N 05° 35.606' W000° 12. 213'	2.59E-03
D	N 05° 35.606' W000° 12. 215'	5.27E-03
E	N 05° 35.604' W000° 12. 216'	2.72E-03
F	N 05° 35.599' W000° 12. 216'	8.86E-04
G	N 05° 35.597' W000° 12. 218'	5.11E-03
H	N 05° 35.595' W000° 12. 215'	5.89E-03
I	N 05° 35.606' W000° 12. 202'	4.82E-03
J	N 05° 35.601' W000° 12. 199'	3.34E-03

Table B18: Measured electric fields at 10 locations at RBS 18

Location	Geographic co-ordinates [GPS]	Electric field $E/\pm 1.03E-03V\text{m}^{-1}$
A	N 05° 35.432 W000° 12. 204'	3.87E-03
B	N 05° 35.431' W000° 12. 202'	5.90E-03
C	N 05° 35.429' W000° 12. 204'	2.74E-03
D	N 05° 35.420' W000° 12. 211'	9.03E-04
E	N 05° 35.425' W000° 12. 211'	8.30E-04
F	N 05° 35.426' W000° 12. 208'	5.85E-04
G	N 05° 35.418' W000° 12. 203'	1.39E-03
H	N 05° 35.427' W000° 12. 194'	1.56E-03
I	N 05° 35.424' W000° 12. 221'	1.96E-03
J	N 05° 35.441' W000° 12. 216'	3.04E-03

Table B19: Measured electric fields at 10 locations at RBS 19

Location	Geographic co-ordinates [GPS]	Electric field $E/\pm 2.39E-03V\text{m}^{-1}$
A	N 05° 34.351' W000° 12. 922'	2.42E-03
B	N 05° 34.355' W000° 12. 928'	7.07E-04
C	N 05° 34.357' W000° 12. 932'	2.13E-03
D	N 05° 34.358' W000° 12. 932'	8.72E-04
E	N 05° 34.353' W000° 12. 924'	2.01E-03
F	N 05° 34.340' W000° 12. 918'	4.98E-03
G	N 05° 34.334' W000° 12. 937'	5.30E-03
H	N 05° 34.340' W000° 12. 923'	4.99E-03
I	N 05° 34.371' W000° 12. 923'	5.31E-03
J	N 05° 34.376' W000° 12. 935'	8.59E-03

Table A20: Measured electric fields at 10 locations at RBS 20

Location	Geographic co-ordinates [GPS]	Electric field $E/$ $\pm 3.30E-03V\text{m}^{-1}$
A	N 05° 35.039' W000° 13. 028'	2.19E-02
B	N 05° 35.038' W000° 13. 026'	9.46E-03
C	N 05° 35.034' W000° 13. 026'	5.56E-03
D	N 05° 35.030' W000° 13. 028'	4.89E-03
E	N 05° 35.036' W000° 13. 026'	3.16E-03
F	N 05° 35.056' W000° 13. 028'	5.73E-04
G	N 05° 35.045' W000° 13. 030'	6.78E-04
H	N 05° 35.050' W000° 13. 039'	5.28E-04
I	N 05° 35.030' W000° 13. 028'	4.16E-03
J	N 05° 35.029' W000° 13. 020'	2.49E-03

APPENDIX C (Spectral for ten different measurement point at rooftop base 4)

Figure A1 Spectrum for location 1 of RBS 4

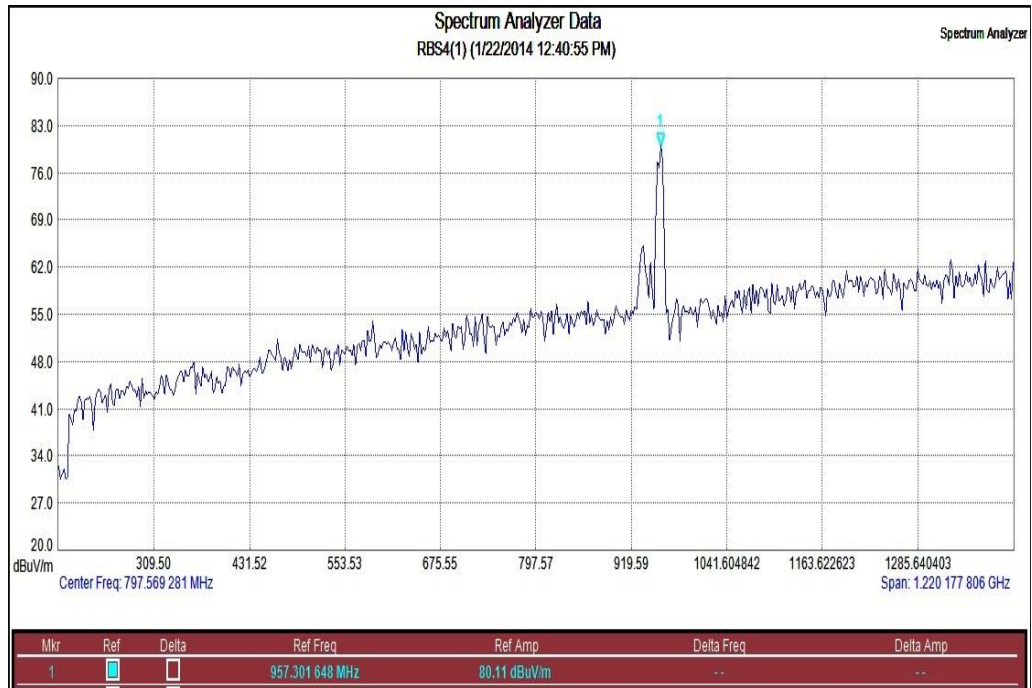


Figure A2 Spectrum for location 2 of RBS 4

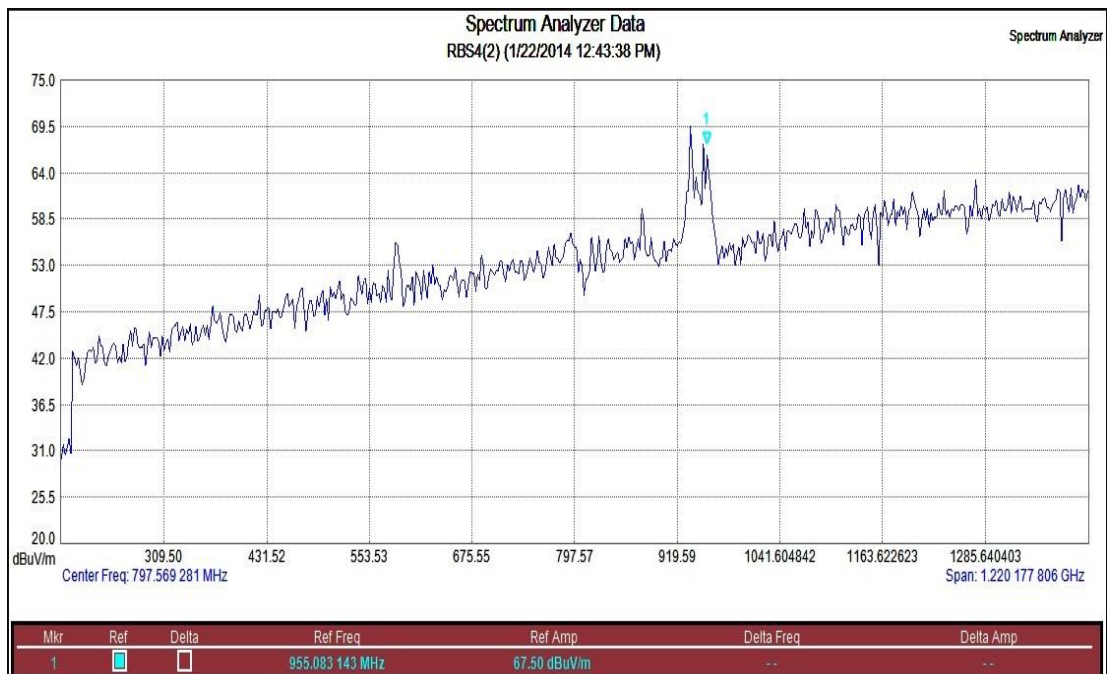


Figure A3 Spectrum for location 3 of RBS 4

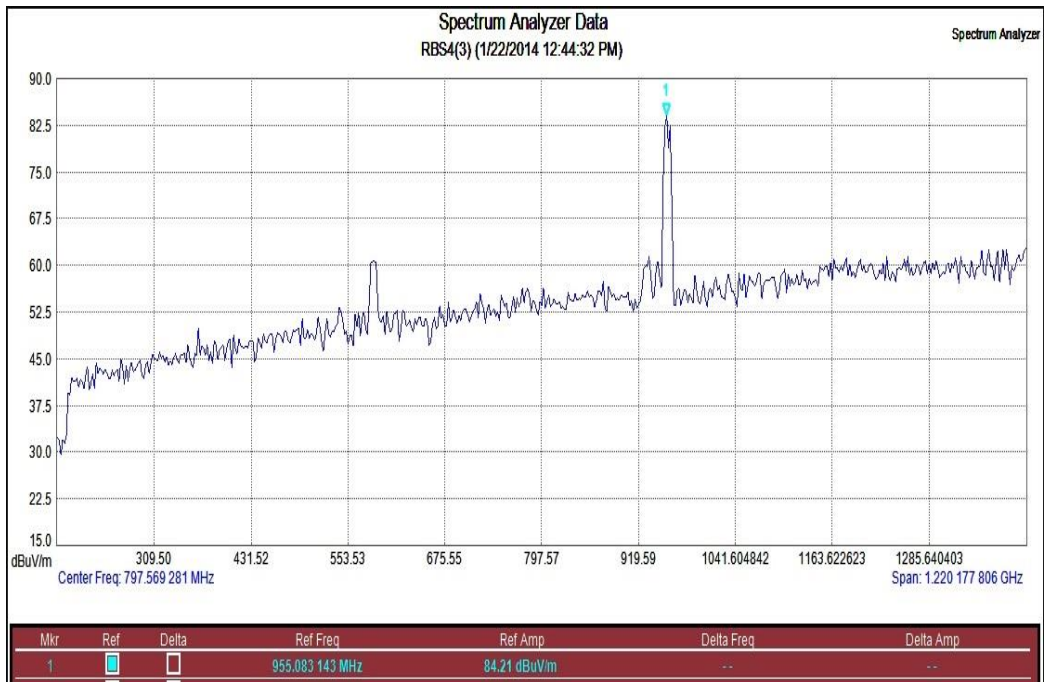


Figure A4 Spectrum for location 4 of RBS 4

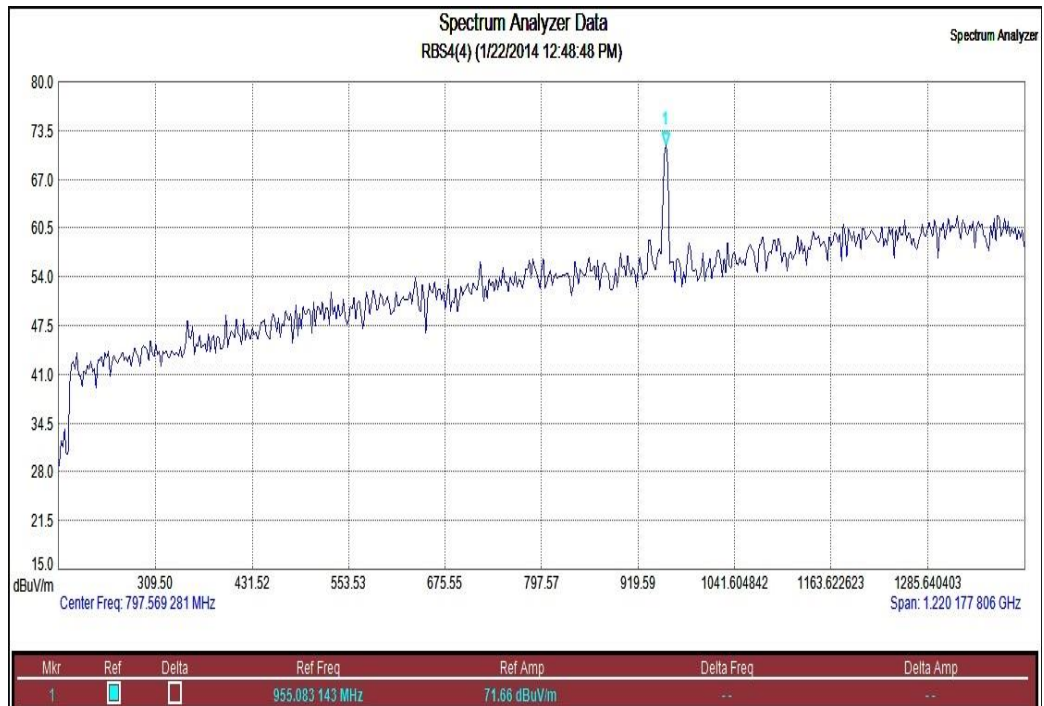


Figure A5 Spectrum for location 5 of RBS 4

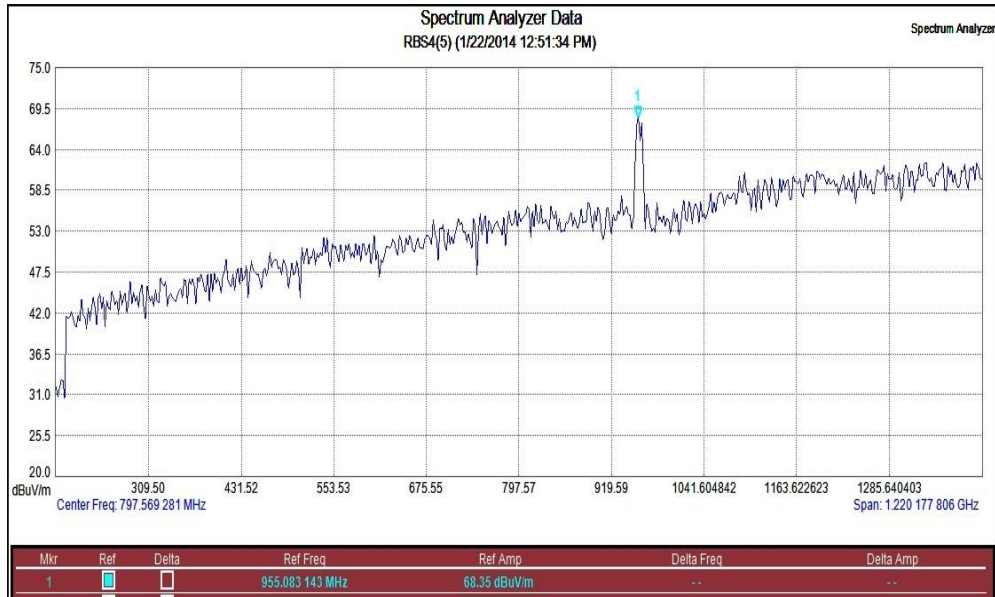


Figure A6 Spectrum for location 6 of RBS 4

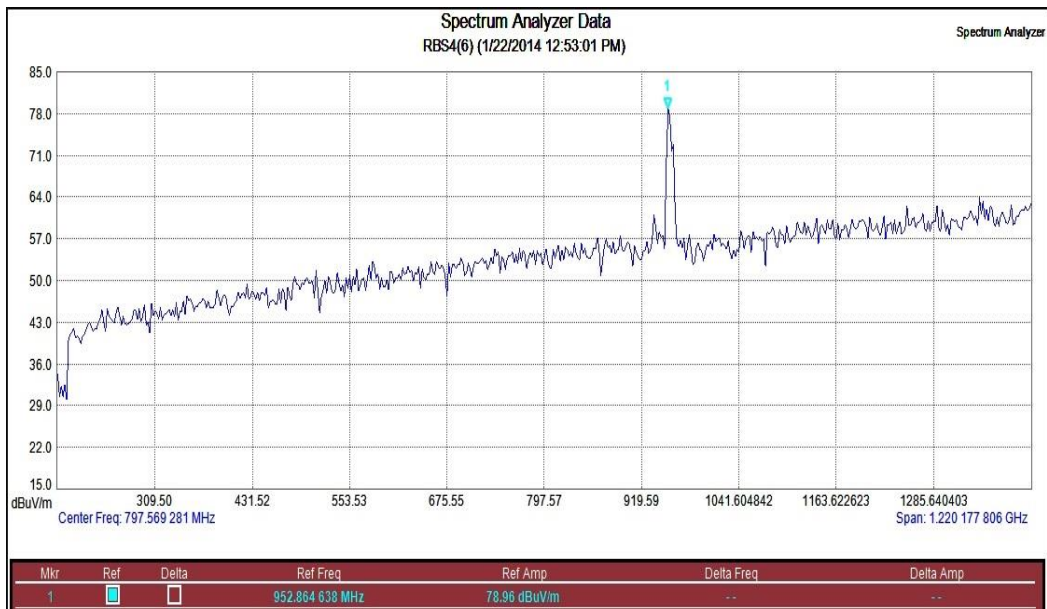


Figure A7 Spectrum for location 7 of RBS 4

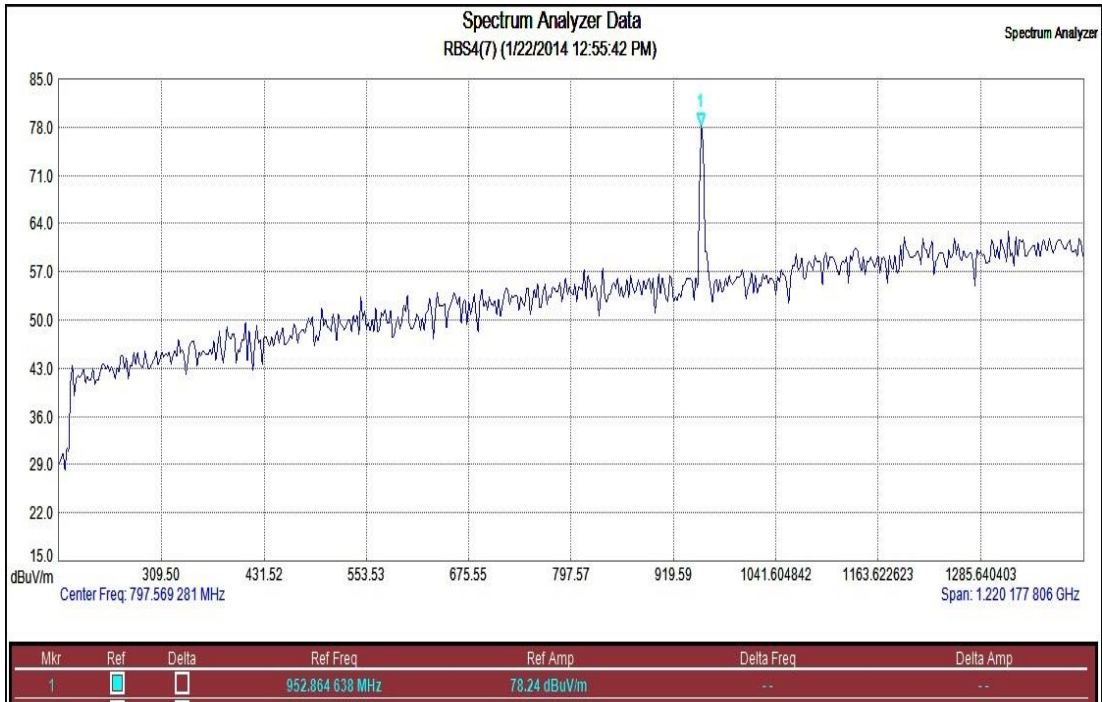


Figure A8 Spectrum for location 8 of RBS 4

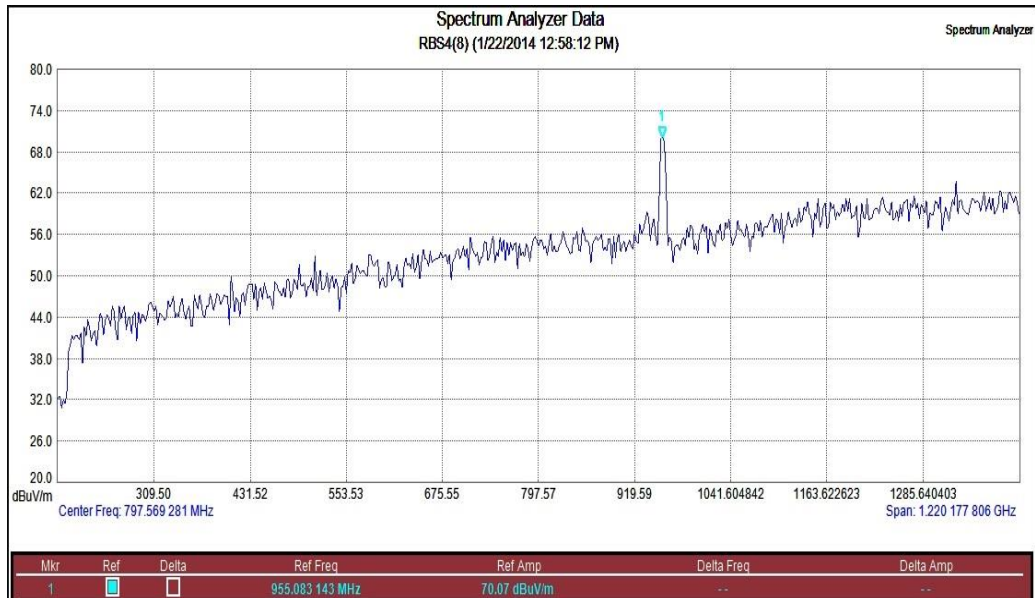


Figure A9 Spectrum for location 9 of RBS 4

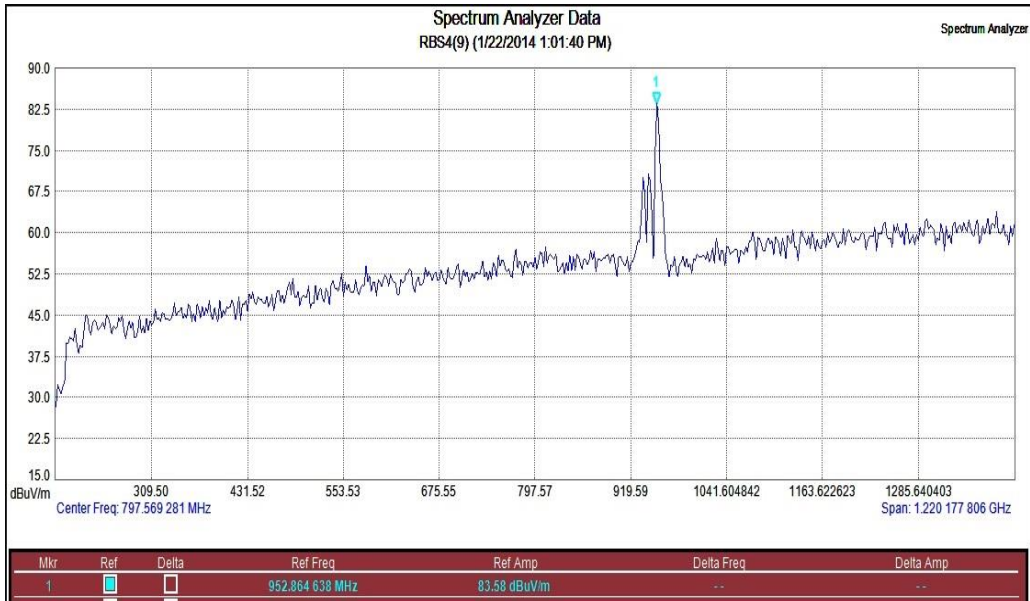
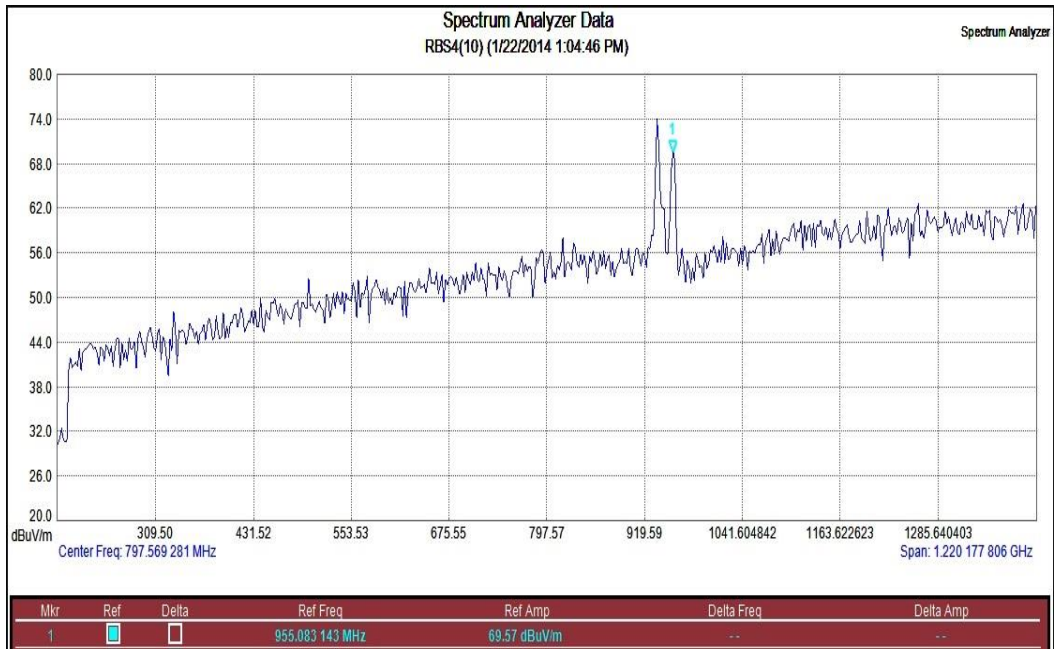


Figure A10 Spectrum for location 10 of RBS 4



**APPENDIX D (GPS coordinates and table of results for both rooftop and tower
base stations)**

Table 1 shows the GPS coordinates of the various rooftop sites.

Roof top Base Station Sites	Geographical GPS Coordinates
RBS 1	N 05° 40.162' W000° 14. 411'
RBS 2	N 05° 39.984' W000° 14. 346'
RBS 3	N 05° 34.999' W000° 12. 988'
RBS 4	N 05° 34.627' W000° 12. 517'
RBS 5	N 05° 33.468' W000° 12. 836'
RBS 6	N 05° 34.295' W000° 12. 944'
RBS 7	N 05° 33.791' W000° 12. 761'
RBS 8	N 05° 40.078' W000° 10. 016'
RBS 9	N 05° 40.249' W000° 09. 900'
RBS 10	N 05°40.122' W 000 °11.346 '
RBS 11	N 05 °38.815' W 000 °11.141 '
RBS 12	N 05 °39.171' W 000 °11.281 '
RBS 13	N 05 °37.122' W 000 °13.821 '
RBS 14	N 05 °35.603' W 000 °11.394 '
RBS 15	N 05 °35.653' W 000 °11.610 '
RBS 16	N 05 °35.879' W 000 °11.871 '
RBS 17	N 05 °35.607' W 000 °12.213 '
RBS 18	N 05 °35.432' W 000 °12.204 '
RBS 19	N 05 °34.345' W 000 °12.934 '
RBS 20	N 05 °36.341' W 000 °13.541 '

Table 2: Maximum and minimum E-field strengths at the various rooftop sites

Rooftop base Station Sites	Maximum E-field Strength (V/m)	Minimum E-field Strength (V/m)
SITE 1	3.84E-03	1.41E-03
SITE 2	1.92E-03	5.68E-04
SITE 3	1.10E-02	1.59E-03
SITE 4	1.62E-02	1.51E-03
SITE 5	1.42E-02	7.70E-04
SITE 6	8.38E-03	1.26E-03
SITE 7	1.32E-02	6.97E-04
SITE 8	5.62E-03	5.86E-04
SITE 9	7.60E-03	6.07E-04
SITE 10	1.36E-02	4.42E-04
SITE 11	1.20E-02	4.73E-04
SITE 12	4.50E-03	4.86E-04
SITE 13	3.46E-03	4.91E-04
SITE 14	1.07E-02	1.05E-03
SITE 15	1.52E-02	2.12E-03
SITE 16	9.07E-03	1.71E-03
SITE 17	1.11E-02	1.60E-03
SITE 18	5.90E-03	5.85E-04
SITE 19	8.60E-03	7.07E-04
SITE 20	1.30E-02	3.73E-04

Table 3: Spatial averages of E-field strengths inside and outside buildings at the various rooftop sites.

Rooftop base Station Sites	Spatial average E-field inside buildings (V/m)	Spatial average E-field outside building (V/m)
SITE 1	1.68E-03	2.85E-03
SITE 2	1.36E-03	1.12E-03
SITE 3	2.81E-03	5.68E-03
SITE 4	5.78E-03	9.89E-03
SITE 5	2.69E-03	6.60E-03
SITE 6	3.83E-03	6.34E-03
SITE 7	5.24E-03	6.89E-03
SITE 8	7.96E-04	3.53E-03
SITE 9	1.06E-03	4.61E-03
SITE 10	1.48E-03	6.38E-03
SITE 11	2.74E-03	6.65E-03
SITE 12	8.46E-04	2.49E-03
SITE 13	1.17E-03	2.10E-03
SITE 14	4.02E-03	4.98E-03
SITE 15	5.98E-03	8.89E-03
SITE 16	1.68E-03	3.73E-03
SITE 17	2.82E-03	5.69E-03
SITE 18	1.53E-03	3.34E-03
SITE 19	2.06E-03	5.61E-03
SITE 20	3.74E-03	7.65E-03

Table 4. shows average power densities levels inside and outside at the various rooftop sites.

Rooftop base Station Sites	Average power densities inside buildings ($\mu\text{W}/\text{m}^2$)	Average power densities outside building ($\mu\text{W}/\text{m}^2$)
SITE 1	0.00747	7.4400
SITE 2	0.00493	0.00335
SITE 3	0.02100	0.08570
SITE 4	0.08860	0.25900
SITE 5	0.01920	0.11600
SITE 6	0.03890	0.10700
SITE 7	0.07270	0.12600
SITE 8	0.00168	0.03310
SITE 9	0.00290	0.05640
SITE 10	0.00577	0.10800
SITE 11	0.11700	0.01990
SITE 12	0.00190	0.01650
SITE 13	0.00363	0.01170
SITE 14	0.04290	0.06580
SITE 15	0.21400	0.09500
SITE 16	0.00745	0.03690
SITE 17	0.00399	0.11100
SITE 18	0.00620	0.02980
SITE 19	0.00272	0.06660
SITE 20	0.24600	0.03270

**Table 5: Exposure quotient of the general public and occupational
Inside and outside buildings at the various rooftop sites.**

Rooftop base Station Sites	Exposure quotient for the public inside buildings	Exposure quotient for the public outside buildings	Exposure quotient for occupational inside buildings	Exposure quotient for occupational outside buildings
SITE 1	1.65E-09	1.65E-06	3.32E-10	3.30E-07
SITE 2	1.09E-09	7.44E-10	4.86E-11	3.31E-11
SITE 3	4.66E-09	1.89E-08	2.06E-10	8.39E-10
SITE 4	1.97E-08	5.76E-08	8.75E-10	2.56E-09
SITE 5	4.26E-09	2.57E-08	1.89E-10	1.14E-09
SITE 6	8.64E-09	2.37E-08	3.84E-10	1.05E-09
SITE 7	1.62E-08	2.80E-08	7.18E-10	1.24E-09
SITE 8	3.74E-10	7.35E-09	1.66E-11	3.27E-10
SITE 9	6.45E-10	1.25E-08	2.86E-11	5.57E-10
SITE 10	1.28E-09	2.40E-08	5.70E-11	1.06E-09
SITE 11	2.59E-08	4.41E-08	1.16E-09	1.97E-10
SITE 12	4.22E-10	3.66E-09	1.87E-11	1.63E-10
SITE 13	8.07E-10	2.61E-09	3.59E-11	1.16E-10
SITE 14	9.52E-09	1.46E-08	4.23E-10	6.50E-10
SITE 15	1.31E-07	2.11E-08	2.11E-09	9.38E-10
SITE 16	1.66E-09	8.19E-09	7.36E-11	3.64E-10
SITE 17	4.67E-08	1.90E-08	2.07E-09	8.46E-10
SITE 18	1.38E-09	6.82E-09	6.13E-11	2.93E-10
SITE 19	6.45E-10	1.25E-08	2.86E-11	5.57E-10
SITE 20	2.60E-08	4.42E-09	1.16E-09	1.97E-10

Table 6: Spatial average E-field strengths for various Tower Base Station Sites

Base Station Sites	Electric field strength (V/m)
SITE 1	9.69E-03 ± 3.70E-03
SITE 2	4.84E-03 ± 1.88E-03
SITE 3	6.73E-03 ± 3.67E-03
SITE 4	9.68E-03 ± 5.31E-03
SITE 5	2.62E-03 ± 9.89E-04
SITE 6	1.09E-02 ± 5.86E-03
SITE 7	1.64E-03 ± 9.19E-04
SITE 8	9.60E-03 ± 5.37E-03
SITE 9	1.94E-03 ± 6.99E-04
SITE 10	7.36E-03 ± 2.63E-03
SITE 11	3.88E-03 ± 1.52E-03
SITE 12	6.73E-03 ± 3.67E-03
SITE 13	5.37E-03 ± 2.45E-03
SITE 14	1.31E-02 ± 1.02E-03
SITE 15	6.90E-03 ± 1.98E-03
SITE 16	3.74E-03 ± 1.17E-03
SITE 17	7.92E-03 ± 4.74E-03
SITE 18	2.91E-03 ± 1.95E-03
SITE 19	9.76E-03 ± 2.57E-03
SITE 20	4.83E-03 ± 2.55E-03

Table 7: Exposure quotients and calculated power densities from the tower base station sites.

Base Station Sites	General Public Exposure Quotient	Occupational Exposure Quotient	Power densities ($\mu\text{W}/\text{m}^2$)
SITE 1	6.23E-08	1.25E-08	0.280
SITE 2	1.38E-08	2.76E-09	0.622
SITE 3	2.67E-08	5.34E-09	0.120
SITE 4	5.53E-08	1.11E-08	0.249
SITE 5	4.24E-09	8.48E-10	0.191
SITE 6	6.97E-08	1.39E-08	0.313
SITE 7	1.58E-09	3.17E-10	0.713
SITE 8	5.43E-08	1.09E-08	0.245
SITE 9	2.22E-09	4.43E-10	0.997
SITE 10	3.20E-08	6.39E-09	0.144
SITE 11	8.88E-09	1.78E-09	0.399
SITE 12	2.67E-08	5.34E-09	0.120
SITE 13	1.70E-08	3.40E-09	0.765
SITE 14	1.01E-07	2.03E-08	0.457
SITE 15	2.82E-08	5.63E-09	0.127
SITE 16	8.25E-09	1.65E-09	0.371
SITE 17	3.69E-08	7.39E-09	0.166
SITE 18	5.97E-09	1.19E-09	0.269
SITE 19	5.62E-08	1.12E-08	0.253
SITE 20	1.37E-08	2.75E-09	0.618