ASSESSMENT OF RADIO-FREQUENCY RADIATION EXPOSURE FROM SELECTED MOBILE BASE STATIONS IN ZARIA AND ENVIRONS, NIGERIA

BY

Sadiya UMAR BSc Physics (UNIJOS) 2010

P14SCPY8007

A DISSERTATION SUBMITTED TO

THE SCHOOL OF POSTGRADUATE STUDIES,

AHMADU BELLO UNIVERSITY,

ZARIA

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF MASTER OF SCIENCE DEGREE IN RADIATION BIOPHYSICS

DEPARTMENT OF PHYSICS

FACULTY OF PHYSICAL SCIENCES

AHMADU BELLO UNIVERSITY,

ZARIA, NIGERIA

APRIL, 2017

DECLARATION

I hereby declare that this thesis entitled "Assessment of Radio-Frequency Radiation Exposure from Selected Mobile Base Stations in Zaria and Environs, Nigeria" has been carried out by me and that it is an account of my own research, except that for reference to other peoples work which have been duly cited in the text. No part of this thesis was previously presented for another degree or diploma at this or any Institution.

Sadiya Umar	_____	_____
Name of Student	Signature	Date

CERTIFICATION

This thesis titled: **Assessment of Radio-Frequency Radiation Exposure from Selected Mobile Base Stations in Zaria and Environs, Nigeria** meets the regulations governing the award of the degree of Master of Science (M.Sc.) of Ahmadu Bello University, and is approved for its contribution to knowledge and literary presentation.

_____	_____	_____
Chairman, Supervisory Committee (Dr. Y.I. Zakari)	Signature	Date
_____	_____	_____
Member, Supervisory Committee (Dr N.N. Garba)	Signature	Date
_____	_____	_____
Head of Department Physics (Dr. Y.I. Zakari)	Signature	Date
_____	_____	_____
Dean, School of Postgraduates Studies (Prof. Kabir Bala)	Signature	Date

DEDICATION

I dedicate this piece of work to Almighty God most merciful, most beneficent for keeping me alive to this day and to my family for their support and encouragement.

ACKNOWLEDGEMENT

I register my immeasurable thanks to Almighty God, who helped me from the beginning to the end of the study. I am very grateful to my supervisors Dr. Y.I Zakari and, Dr. N.N. Garba for their immense efforts, hard work, guideline, suggestions, advice, tolerance and patience throughout the period of my research study. May Allah reward you abundantly. I appreciate you.

My warm appreciation goes to the entire Academic staff of the Department of Physics especially Dr. U. Sadiq, Prof. (Mrs) I.G.E Ibeanu and Dr. Y.A. Yusuf for their words of encouragement and advice.

I am indeed grateful to Engr Mustapha and Engr Mathew of the Electronics and Telecommunication unit of Faculty of Engineering for their guide and hard work during my field work. A special thanks to the Head of Engineering Department and the technical staff of electronics and telecommunication section of the Department of Engineering, Ahmadu Bello University Zaria, for their support.

I extend my gratitude to my family for their patience and support throughout the course of this work. A special thanks to my friends, colleagues, well wishers, senior classmates and Malam Ibrahim Bello Deji who have assisted me in one way or the other. May Amighty God reward you.

ABSTRACT

Base transceiver stations (BTS) or mobile base stations produce non-ionizing (RF) energy that is radiated through its antennas into space. There are health effects that can occur when the human body is exposed to high levels of radio frequency (RF) energy. The health implication associated with exposure from telecommunication masts is demanding attention due to the expansion of telecommunication networks and base station installation. In this study, power density from various telecommunication masts of different network providers were measured using a spectrum analyser 2658A B and K precision model. RF radiations within a radial distance of 100 m around some selected areas in Kaduna State were measured. The measured values range between 9.29 nWm^{-2} to 58.08 nWm^{-2} with a mean value of 23.52 nWm^{-2}. Although values fluctuated due to the influence of other factors including wave interference from other electromagnetic sources around reference base stations. The results show that radiation exposure level is below the standard limit of 4.5 Wm^{-2} for 900 MHz system set by the International Commission on Non-ionizing Radiation Protection (ICNIRP) and other regulatory agencies. This shows that the exposure levels in these areas are low and as such will not pose significant health risks to the people living in the study area.

.

TABLE OF CONTENTS

Title Page	i
Declaration	ii
Certification	iii
Dedication	iv
Acknowledgement	v
Abstract	vi
Table of Contents	vii
List of Tables	xi
List of Figures	xii
List of Abreviations in Order of Application	xiv
Appendices	xv
CHAPTER ONE	1
INTRODUCTION	1
1.0 Introduction	1
1.1 Background of the study	2
1.2 Statement of the Research Problem	5
1.3 Aim and Objective of the Study	6
1.4 Justification	6
1.5 Scope and Limitation	7
CHAPTER TWO	8
LITERATURE REVIEW	8
2.1 Communication Antennas	8
2.1.1 Near and Far Field Regions of an Antenna	12
2.1.2 History of Communication Antennas	12
2.2 Types of Antennas	13
2.2.1 The Dipole Antenna	13

2.2.1.1 Standing Waves in Dipole Antennas 14
2.2.1.2 Quarter-Wave Dipole Antenna 14
2.2.1.3 Half-wave dipole antenna 15
2.2.1.4 Efficiency of an antenna: 15
2.2.2 Omnidirectional and Sector Antennas 16
2.2.3 Directional Antennas 16
2.2.4 Wire Loop Antennas 18
2.3 Radiation 19
2.3.1 Ionizing Radiation 19
2.3.2 Non Ionizing Radiation 20
2.3.2.1 Thermal Effects 21
2.3.2.2 Non-Thermal Effects 22
2.4 The Electromagnetic Spectrum 22
2.4.1 Ultra Violet 23
2.4.2 Visible Light 23
2.4.3 Infra Red 24
2.4.4 Microwave 24
2.4.5 Radio Waves 25
2.4.5.1 Radio Wave Propagation 26
2.4.5.2 Radio Wave Propagation on Earth 28
2.4.6. Maxwell's Equations 29
2.5 Radiated Power Density 32
2.6.1 Effect on Cell Membrane Ca^{2+} 34
2.6.2 Effect on DNA 35
2.6.3 Blood Brain Barrier 36
2.6.4 Irreversible Infertility. 37
2.6.5 Autism 38

2.6.6 Risk to Children and Pregnant Women 38
2.6.7 Effect on Electromagnetic Property of Human Cell 39
2.6.8 Effect on Birds 41
2.6.9 Effect on Plants 42
2.6.10 Interference with other Gadgets like Pace Maker 42
2.6.11 Heat-Shock Proteins 42
2.7 RF Exposure Guidelines 43
2.8 Review of Previous Works 46
CHAPTER THREE 52
MATERIALS AND METHODS 52
3.1 Materials 52
3.2 Methodology 52
3.2.1 Study Area 52
3.2.2 Data collection 55
3.3.3 Data Analysis 59
3.4 Instrumentation 59
3.4.1 Spectrum Analyser 59
3.4.2 Principle of operation 61
CHAPTER FOUR 62
RESULTS AND DISCUSSION 62
4.1 Results 62
4.2 Discussion 70
CHAPTER FIVE 76
CONCLUSION, SUMMARY AND RECOMMENDATION 76
5.1 Conclusion 76
5.2 Summary 76
5.3 Recommendation 77

REFERENCES 78

APPENDICES 84

LIST OF TABLES

Table 2. 1: Countries and Guidelines (Ekata, 2015) 44

Table 2. 2: National and International Guidelines Exposure levels to GSM and TETRA 45

Table 3. 1: Description of the study area 53

Table 4. 1: Power density at different distances 63

Table 4.2 : Power density at 1600 m away from the transmitting antenna for B14 and B15 63

Table 4. 3: Average power density within 100 m radius for all locations B1 to B13 64

Table 4. 4: Radiation level from B1 65

Table 4. 5: Radiation level from B2 65

Table 4. 6: Radiation level from B3 66

Table 4. 7: Radiation level from B4 66

Table 4. 8: Radiation level from B5 66

Table 4. 9: Radiation level from B6 67

Table 4. 10: Radiation level from B7 67

Table 4. 11: Radiation level from B8 67

Table 4. 12: Radiation level from B9 68

Table 4. 13: Radiation level from B10 68

Table 4. 14: Radiation level from B11 68

Table 4. 15: Radiation level from B12 69

Table 4. 16: Radiation level from B13 69

Table 4. 17: Average Absorbed Radiation Level 69

LIST OF FIGURES

Figure 2. 1: Directionality and gain of a Yagi antenna (Kyle, 2004) 18

Figure 2. 2: Electromagnetic Spectrum (Climate Science Investigation, 2016) 26

Figure 3. 1: Map of the study area 54

Figure 4. 1: Power density at different distances for all locations 70

Figure 4. 2: Average power density at 20 m interval for locations B1 to B13 72

Figure 4. 3: Absorbed radiated power by human body at different distances. 74

LIST OF PLATES

Plate 3.1: Power density measurement using spectrum analyser 2658A model 57

Plate 3. 2: Measurement from the foot of the antenna inside the BTS behind Faculty of Veterinary Medicine, Ahmadu Bello University. 58

Plate 3. 3: Spectrum analyzer 2658A 60

Plate 3. 4: Spectrum analyser 2658A showing power mode 60

LIST OF ABREVIATIONS IN ORDER OF APPLICATION

BTS - Mobile Base Transceiver Stations

GSM - Global System of Mobile communication

RF - Radio Frequency

EMF - Electromagnetic Fields

MPE - Maximum Permissible Exposure

ICNIRP - International Commission for Non Ionizing Radiation Protection

RFID - Radio-Frequency Identification

CDMA - Code Division Multiple Access

EMW - Electromagnetic Waves

UMTS - Universal Mobile Telecommunications System

DTX - Discontinuous Transmission

AM - Amplitude Modulation

MHz - Mega Hertz

GHz - Giga Hertz

SWR – Standing Wave Ratio

dB - Decibel

dBm – Decibel milliwatt

NIR - Non Ionizing Radiation

APPENDICES

APPENDIX A: Measured Radiated Power Table (dBm) 84

APPENDIX B: Conversion Tables 85

CHAPTER ONE

INTRODUCTION

1.0 Introduction

Mobile phone technology has revolutionized the telecommunication industry in Nigeria. Due to its advantages, mobile phone technology has grown rapidly in the last decade. Presently, there exist more than 6.9 billion mobile subscription globally and over 1.4 million mobile base transceiver stations (BTS) exist worldwide to meet the growing communication demand and the number is increasing significantly (WHO, 2006).The Global System of Mobile (GSM) communication has proved to be of tremendous benefit to the society especially in a developing country like Nigeria, where other forms of communication exist to a very limited extent. GSM technology of wireless communication produces constant pulsed microwave radiation. The cellular base stations are transmitting continuously even when nobody is using the phone. The number of cell towers is massively increasing without taking into consideration its disadvantages. The risk associated with the radiation emitted from base transceiver stations with respect to its proximity to residential and other public areas were of great concern worlwide. The radiation effects on humans are divided into thermal and non-thermal effects. Thermal effects are similar to that of cooking in the microwave oven. Non thermal effects are not well defined but it has been reported that it is about 3 to 4 times greater than thermal effects. Radiation emitted from telecommunication mast is also harmful to the environment by adding to the background radiation and also have negative effect on plants and animals (Girish, 2010).

1.1 Background of the study

A BTS is a component of a wireless communication infrastructure that houses the radio that defines a cell and coordinates the radio link protocols with mobile devices such as GSM phones. A typical BTS consists of radios, amplifiers, combiners, duplexers, splitters, power supplies, an antenna system, and the software that runs the base station (Godfrey, 2015).

Telecommunication masts or towers are tall structures designed to support antennas or aerials responsible for the transmission of telecommunication signal. These masts make use of electromagnetic radiation (a form of energy which have both electric and magnetic component and is propagated through space) in transmission of this signal. Erection of cellular telecommunication antennas close to or even upon schools, daycares, retirement homes and residential buildings that affect the health and wellbeing of everybody. The erection of these antennas has created lots of problem between families and friends, tenants and landlords due to the huge amount of money accrued to leasing or selling of land to telecommunication companies for the purpose of installation of telecommunication mast at the detriment of their health and the needed luxury of space for proper ventilation. It has been mentioned that we are now virtually living within a microwave oven (Andrew, 2008). Although the effects of the radiation that mobile phone towers emit are harmful and above all it has not been proved safe by the telecommunication companies, there are more and more towers being approved by the municipal governments (Andrew, 2008).Scientifically, there were several reports that the electromagnetic radiation released by mobile telecommunications, has now become the main man-made source of environmental radioactivity (Andrew, 2008).



Figure 1.1: Telecommunication mast (Dreamstime, 2016)

The negative effects of non ionizing radiation have been reported by scientists. George Carlo demonstrated the unwillingness of the cell phone companies to admit in public the results and to be responsible for the impacts this technology has in the human body in his book “Cell phones invisible hazards in the wireless age”(Andrea, 2007).The biggest immediate concern is that the cellular telecommunications companies are targeting the younger generation. These particular groups of people have thinner skulls which do not block as much radiation as an adult's skull does, a more sensitive nervous system, not such a strong immune system, an increased rate of cell division, which is the reason why cell damages spread faster (Andrea, 2007).

Living closer to a cell phone antenna, can cause in children more than in any other group of people; cancer, loss of memory, attention and concentration disorders, sleep disorders, mental disorders and hyperactivity among others (Eltiti *et al*, 2007).

In Valladolid, Spain, a cellular telecommunications antenna had to be removed after 11 children have been diagnosed with cancer within a short period of time (Eltiti *et al*, 2007). In New Zealand, cell phone towers are prohibited close to schools due to possible health hazards such as learning disabilities and brain tumors. Furthermore, studies by Prof. Roger Santini, France and Prof. A. Enrique Navarro, Spain and others, proved that the symptoms of illness found within a radius of between 300-400 meters from mobile telephone transmitters as the so-called microwave syndrome. This includes sleep disturbances, headaches, exhaustion, headaches, impaired concentration, tinnitus, heat sensations on the ears and many other effects (Eltiti *et al*, 2007).

A number of countries have developed and/or adopted national or international guidelines for checking and ensuring that emissions from installed wireless communication systems conform to electromagnetic field (EMF) safety levels. The adopted guidelines specify the maximum permissible exposure (MPE) limits of EMF or radio frequency (RF) energy that may be allowed into the environment for the general public. The International Commission for Non-Ionizing Radiation Protection (ICNIRP) standards and guidelines are widely used for setting national standards to restrict human bodies to EMF exposure (LEAC, 2010). Exposure standards usually referred to electric and magnetic component or power density limits. They are individually measured when it is required by the field properties related to the field regions. Nigeria, through an act of its National Assembly, is poised to adopt the ICNIRP standard.

1.2 Statement of the Research Problem

The radiations emitted from antenna are non-ionizing, as the energy is too low to cause direct ionization which can break chemical bonds in biological systems. But exposure to these radiations over a long period of time may become harmful (Bhat, 2013). In general the exposure to electromagnetic waves (EMW) from different sources is divided into two categories ”continuous” and ”pulsed” according to the characteristics of the emitted waves. The biological effect of pulsed wave exposure are even more harmful than that of the continuous variety from other sources (Bhat, 2013).There are health effects that can occur when the human body is exposed to high levels of radio frequency (RF) energy. Base transceiver stations (BTS) or mobile base stations produce non-ionizing RF energy that is radiated through its antennas into space. Although the amount of RF energy emitted by a base station is relatively low to constitute health hazards to humans, a poorly installed or configured BTS could stray from the envisioned operating standards and function out of compliance, thus emitting high level of RF energy that exposes humans and equipment to unsafe radiation and its attendant hazards.

Some of the biological effects are thermal effects that affects the eyes and the male testes, non thermal effects may affect in vivo cell membrane structure and function. Besides, the BTS is an emitter of electromagnetic fields (EMF), which can exceed the safety limits depending on the operating power, power gain, frequency, orientation, and directivity of the transmitting antenna” (ITU, 2009). Spurious emissions by unintentional emitters can also cause telecommunications equipment to produce EMF. However, such unintentional emitters do not need any EMF safety assessment to assure BTS compliance with safety limits (ITU, 2009). Inhabitants living near mobile phone

base stations suffered from frequent headaches, memory changes, dizziness, tremors, depressive syndrome and sleep disturbance (Bevelaqua, 2015*).*

1.3 Aim and Objective of the Study

The aim of this work is to assess radio-frequency radiation exposure level from selected mobile base stations of telecommunication networks.

This work is therefore set out to achieve the following objectives.

- To evaluate Radio-Frequency Radiation Exposure Level by measuring Power Density from Selected Mobile Base Stations (MBS) in three Local Governments.
- To analyse the radiation power density (in W/m^2) from mobile base stations relative to radial distance (in metre).
- To determine whether or not the radio frequency emissions from serving BTSs exceed the maximum permissible exposure limits.
- To assess the safety limits of the proximity of base stations to both residential and official residences.

1.4 Justification

Since people are exposed to various types of non ionizing radiations depending on their sources, effects and penetrating power, in particular, effects of radio-wave and microwaves emitted by communication antennas erected within living areas. It is imperative that we assess the situation in relation to health related problems that the public may be exposed to, and to draw their attention and that of the government to it.

1.5 Scope and Limitation

This research will cover some selected telecommunication masts and is limited to only those within Sabon gari, Zaria and Giwa local government areas of Kaduna state.

CHAPTER TWO

LITERATURE REVIEW

2.1 Communication Antennas

An antenna is a device used for converting electromagnetic radiation in space into electrical currents in conductors and vice versa, depending on whether it is being used for receiving or transmitting respectively. Electricity flowing into the transmitter antenna makes electrons vibrate up and down in it, producing radio wave which travels through the air at the speed of light. When these waves arrive at the receiver antenna, they cause electrons to vibrate inside the receiver. This produces an electrical current that recreates the original signal. Antennas are essential components of all equipments that use radio. They are used in systems such as radio broadcasting, broad cast television, two-way radio, communications receivers, radar, cell phones, satellite communications, as well as other devices such as garage door openers, wireless microphones, bluetooth-enabled devices, wireless computer networks, baby monitors, and Radio-Frequency Identification (RFID) tags on merchandise. (Carolyn, 2007)

A communication antenna consists of arrangement of metallic conductors electrically connected to the receiver or transmitter. An oscillating current of electrons forced through the antenna by a transmitter will, create an oscillating magnetic field around the antenna elements, while the charge of electrons also creates an oscillating electric field along the elements. These time varying fields radiate away from the antenna into space as a moving transverse electromagnetic field wave. Conversely during reception the oscillating electric and magnetic fields of incoming radio wave exert force on the electrons in the antenna elements causing them to move back and forth, creating oscillating currents in the antenna. Communication antennas can be designed to receive

and transmit radio waves in all horizontal directions equally (omnidirectional antenna), or in a particular direction (directional or high gain antenna). Radio waves are electromagnetic waves which carry signal through the air (or space) at the speed of light with almost no transmission loss (Schantz. 2003)

Telecommunication antennas demonstrate a property known as reciprocity, which means that an antenna will maintain the same characteristics regardless if it is transmitting or receiving. Most antennas are resonant devices, which operate efficiently over a relatively narrow frequency band. An antenna must be tuned to the same frequency band of the radio system to which it is connected; otherwise the reception and the transmission will be impaired. When a signal is fed into an antenna, the antenna will emit radiation distributed in space in a certain way. A graphical representation of the relative distribution of the radiated power in space is called a radiation pattern.

Mobile tower antennas transmit in the frequency range of 869-894 MHz (CDMA), 935-960MHz (GSM 900) and 1810-1880 MHz (GSM 1800). Also 3G has been deployed in some areas in which base station antennas transmit in the frequency range of 2110-2170 MHz. Mobile phone operators divide a region in large number of cells, and each cell is divided into number of sectors. The base stations are normally configured to transmit different signals into each of these sectors. In general there may be three sectors with equal angular coverage of 120 degrees in the horizontal direction as this is a convenient way to divide a hexagonal cell. If number of users is distributed unevenly in the surrounding area, then the sectors may be uneven. These base stations are normally connected to directional antennas that are mounted on roofs of buildings or on free standing masts. The antennas may have electrical or mechanical down tilt so that the signals are directed towards the ground level. A base station and its transmitting power

are designed in such a way that mobile phone should be able to transmit and receive enough signal for proper communication up to a few kilometers.

Majority of these towers are mounted near residential or office buildings to provide good mobile network coverage to the users. These base transceiver stations transmit radiations all the time. So people living within 10's of meters from the tower will receive 10,000 to 10,000,000 time's stronger signal than required for mobile communication (Girish, 2010). In Nigeria many people reside within these high radiation zones.

GSM antennas will either be directional or non-directional. Non-directional antennas, also known as helical antennas, can receive signals from any direction; they are essentially employed for broadcast transmission and reception (Lai *et al*, 1996). Directional antennas usually have more gain, that is, more sensitivity to signal, than non-directional antennas. Directional antennas accomplish this greater sensitivity because they are able to focus their energy patterns onto a smaller area than non-directional antennas. However, to receive signal, directional antennas must be pointed in the specific direction from which the signal is emanating. By doing so, directional antenna will be able to transmit and receive maximum energy in one direction only. Consequently, directional antennas are used for radio telephony and other point to point links.

A radio frequency (RF) electromagnetic wave (EMW) has both an electric and magnetic fields. Different forms of electromagnetic energy are categorized by their wavelengths and frequencies. The RF part of the electromagnetic spectrum is generally defined as that part of the spectrum where EMW have frequencies in the range of about 3 kilohertz (3 KHz) to 300 gigahertz (300GHz). Microwaves are specific categories of radio waves

that can be loosely defined as RF energy at frequencies ranging from about 1 GHz and above (Blettner et *al.* 2008).

GSM 900 system has been allotted two frequency bands, 890-915 MHz for the uplink (mobile phone to base station) and 935-960 MHz for the downlink (base station to phone) system. The downlink of a particular channel is 45 MHz higher than the uplink (duplex operation) (Firstenberg. 1997). The GSM 1800 system uses bands of 1710-1785 and 1805-1880 MHz, respectively. The 1st generation (analog) systems use frequency bands around 450 and 900 MHz, while the coming Universal Mobile Telecommunications System (UMTS) is allocated bands of 1900-2025 and 2110-2200 MHz. Emissions from these systems are not included in this evaluation only GSM 900 MHz system was used. In the GSM systems, each link is allocated a bandwidth of 200 kHz (0.2 MHz). Thus, the allocated spectrum could theoretically encompass 124 (GSM 900) or 374 (GSM 1800) different channels (pairs of links) (Girish, 2010). However, the need to have a few cell's separation between re-use of the same frequency, and the fact that a single operator is usually only allocated a part of the frequency band, limit the number of possible channels to be used in each cell, and thus also the total emitted power. One channel (the control channel) from each base station is always transmitting with essentially a constant power regardless of the traffic intensity. Other channels (traffic channels) do only send when the traffic requires, and may also use a power regulation system. Accordingly, the emitted power from a base station may vary over the day and week from a minimal power of e.g. 10W during period with low to modest traffic, to perhaps up to 5 times that level at peak traffic (if there are four traffic channels in addition to the control channel) (Fejes *et al,* 2006). From a GSM base station with more than one channel, there are thus a variety of reasons for variations in the transmitted power at any given time: how many channels are in use, how many of

the time slots in the traffic channels are used, and whether discontinuous transmission (DTX) is used or not. Any attempt to characterise the exposure around a base station should take this traffic-dependent time-variation into account. Information from the operator of the base station on traffic statistics could provide a basis on how this should be done. Options could include sampling (for average situation) and choosing a probable maximum traffic time (for worst case situation).

2.1.1 Near and Far Field Regions of an Antenna

The exposure from telecommunication mast can be classified as near field or far field depending on its position to the antenna. Near field is the region in the field of the antenna that is located close to the antenna and the electric and magnetic field do not have a substantial plane wave character but varies from point to point. On the other hand the far field is the region of the antenna in which the angular field distribution does not depend on the distance from the antenna (Dina,2000) and the field is used for assessing public exposure level and the radiation intensity reduces with distance thus obeying the inverse square law (Bolaji and Idowu, 2012).

2.1.2 History of Communication Antennas

The study of wireless communication started from mid 1800s and much evolution had occurred since. The first experiments with wireless communication are on record in 1867 but little details are available. A major breakthrough is noted for Guglielmo Marconi with a wireless call that travelled to boats across the Atlantic Ocean (Kyle, 2004). Previous to this feat radio transitions had a very limited range such that houses or boats very close could talk to each other, but communication over great distances was unlikely. Radio communication was only a series of tones, known as mores code, but it now provided the ship industry with an element of safety that it do not have before Marconi.

The next breakthrough was in 1916 when operators at Radio Arlington were able to transmit the sound of a human voice up and down the Atlantic coast. This was a major breakthrough and the beginning of AM (Amplitude Modulation) radio. This sparked an interest in radio and during the mid 1920s many citizens were putting wire array antennas on their roofs to talk to other people nearby. The frequencies used by citizens were in the high frequency range lower than 200 meters wavelength. Because of this, people who use this band are known as shortwave or "ham" operators. People quickly realized that the shorter the wave the further it propagates through space. Therefore people operating in the range below 50 meters were able to make contact around the world in the early 1920s (Eltiti *et al*, 2008).

2.2 Types of Antennas

There are basically six types of antennas namely; isotropic, monopole, dipole, array, loop and aperture depending on their functions.

2.2.1 The Dipole Antenna

One of the simplest and oldest type of antennas is the Dipole of Hertzian antenna. This type of antenna is characterized by two radiators placed in line with each other. This antenna was first used by Heinrich Hertz who is considered to be the father of modern day radio. The length of the radiators is determined by the wavelength. Each wavelength must be ¼ of the desired frequency for optimal power delivery. Therefore the length of each radiator is determined by Equation (2.1) where f is the frequency in MHz and L is the radiator length in feet (Kyle, 2004)

$$L = \frac{468\text{ft}}{\text{f}} \qquad \text{(Kyle, 2004)} \qquad (2.1)$$

The length is not the only feature of interest in making an efficient antenna. Antennas act as a RLC network with varying impedances dependent on the frequency of interest.

At some frequencies the antenna acts as an inductor and at others it acts as a capacitor. The perfect antenna will be one in which the capacitance and inductive characteristics will cancel each other out. This is called a resonant antenna. An efficient antenna is one which is resistive and resonant. Dipole antennas are coupled to transmitters by a transmission line which is connected between the radiators.

The input of an antenna can be easily calculated using the power law derived from Ohms law.

$$R = \frac{P}{I^2} \tag{2.2}$$

R = resistance

I = current

P = power

It is essential to match the antenna input resistance with both the transmission line and the transmitter output. Typical input resistances for dipole antennas are between 60 and 90 ohms, but it is interesting to note that the antenna resistance will vary with outside conditions such as weather and nearby objects.

2.2.1.1 Standing Waves in Dipole Antennas

A measure of the standing wave ratio (SWR) is calculated by taking a ratio of Z_0, the transmission line resistance, and R, the antenna resistance.

$$\text{SWR} = \frac{Z_0}{R} \tag{2.3}$$

2.2.1.2 Quarter-Wave Dipole Antenna

The dipole antenna acts as an isotropic point source, radiating its energy in all directions. This characteristic makes the antenna omni directional in respect to coverage

area of the radiated signal. Radiation and directivity can be expressed as directive gain which is the ratio of the power density that is radiated by the antenna to the average power density. This is determined by (2.4)

$$G = \frac{4\pi r^2(\vec{S})}{P_{rad}} \tag{2.4}$$

S is the average power density.

2.2.1.3 Half-wave dipole antenna

When more power is needed to be dissipated by the antenna a half wave or full wave antenna is appropriate. Increasing the antenna length also increases the amount of current that can be supplied to the center tap (Kyle, 2004).

2.2.1.4 Efficiency of an antenna:

The efficiency of an antenna is directly related to its total resistance and the power which is delivered to it. The total resistance is the sum of the connector resistance as well as the resistance due to radiation. The power delivered to the antenna is defined by

$$P_{rad} = \frac{1}{2} I^2 R_{rad} \tag{2.5}$$

where I is the current delivered and R_{rad} is the total antenna resistance. The power radiated by the antenna is related to the resistance of radiation.

$$\eta_e = \frac{P_{rad}}{P_{in}} = \frac{R_{rad}}{R_a} \frac{R_{rad}}{R_c + R_{rad}} \tag{2.6}$$

The efficiency of the antenna is the ratio of power radiated and the power delivered to the antenna (Kyle, 2004).

2.2.2 Omnidirectional and Sector Antennas

Omni antennas radiate in every direction, while sector antennas effectively only radiate in a (horizontal) sector. Example of omni directional antennas are the monopole antennas and have equal gain in all directions. This will permit increased re-use of frequencies, as it will reduce interference – accordingly, most base stations in high traffic density areas such as cities are of the sector type. The preferred sector antenna gain is between 10 and 20 dBi – this means that the emitted power may be between 10 – 100 times stronger in the intended directions compared to an omni antenna, while it will be correspondingly weaker in other directions (Blettner *et al.* 2008). For example, the exposure behind a sector antenna could be 300 times weaker than in the main lobe. In addition to this horizontal directionality, the antenna lobe will also have a strong vertical directionality, with a fairly narrow beam, which is often tilted slightly downward (Wojcik *et al.* 2005). At a sufficient distance from the antenna (of at least 10-15 meters) the EMF exposure levels can be characterized by the power density in W/m^2. In the main lobe, and disregarding attenuation by other objects (free space), this power density will decrease with the square of the distance. On the ground, however, this distance variation will be more complex, as the highest level will be found at a distance from the antenna where the main lobe reaches the ground. Closer to the antenna, the ground level will be substantially lower than in the main lobe. Due to the existence of side lobes, the actual variation with distance could be rather complicated. Similarly complicated variations can also be found indoors (Bergqvist *et al.* 2001).

2.2.3 Directional Antennas

Sometimes radio signals need only be focused in a single direction. When this is the application, a directional antenna rather than an omni directional antenna is better suited for the job. The most common directional antenna is called a Yagi-Uda antenna because

it is very effective at radiating energy in a single direction. The Yagi antenna is typically a half wavelength type and has three radiating elements instead of a single dipole radiating element. The antenna has a single driver that is fed at a center tap similar to a dipole. In addition there are a minimum of two additional elements coupled to the driver. These elements act as reflectors which absorb energy from the main radiating element and channel it back to the feed point to be redirected in the desired direction. The reflector elements are typically 5 % longer than the length of the main radiating element. The spacing between the radiator and the reflectors is typically 0.2m (Kyle, 2004).

Figure 2.1 shows a directivity graph that would be typical of the performance of a Yagi antenna. In the figure the angle between the line of propagation to the beam edge is the angle of directionality, or the angle between 0 and -3dB. The main lobe of radiation is much greater than the secondary or side lobes. Depending on the efficiency of the antenna the main lobe can be between 20 and 40 dB higher than the omni directional equivalent.

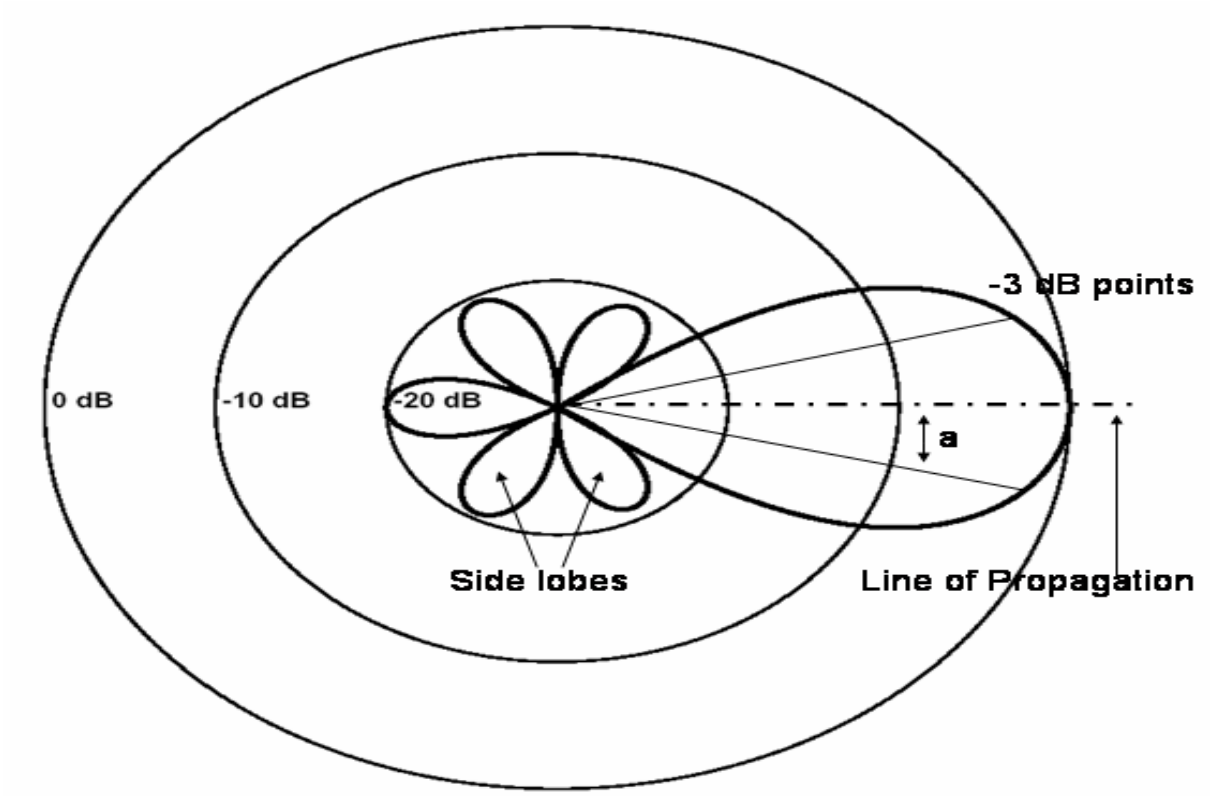


Figure 2. 1: **Directionality and gain of a Yagi antenna (Kyle, 2004)**

2.2.4 Wire Loop Antennas

A third common type of antenna is a wire loop. This antenna differs from both dipole and directional in that it is less efficient, but it has some unique characteristics that allow it to be used for specific applications. Wire loop antennas are classified as being large or small depending on the size of the loops. A small loop antenna refers to an antenna in which the length or a single loop is less than 0.2 m in length. A large loop antenna is therefore any antenna with a loop larger than 0.2 m. The main difference between the loop antennas in terms of electromagnetic is that the current varies along the wire of a large loop antenna. Also because the large loop antenna is typically one wire in density the feed point is at a point where the voltage potential is a maximum. This results in a feed point with a resistance in the order of 1 kilo ohm. Wire loop

antennas generate and receive magnetic flux around the outside of their coils. This characteristic allows the antennas to be directional, or used to determine the direction in which a signal is being received. Taking advantage of this electromagnetic characteristic allows this antenna to reject noise or track a signal when used on a receiver or send a semi-directional signal in a compact environment when used on a transmitter (Kyle, 2004).

2.3 Radiation

Radiation is the emission of streams of particles such as electrons, protons, high energy photons or an emission of a combination of these (Parker, 1989). Radiation is everywhere in our environment it has been since, from outer space, the ground and even from our bodies. In other words, we are naturally exposed to radiation from the moment we are conceived to the moment we die. Radiation is invisible and not directly detectable by human senses. Though with some advantages presents a health hazard, if used improperly can cause damage to living tissue. Hence man is able to affect or change his environment positively or negatively. There are two types of radiation; ionizing and non-ionizing radiation.

2.3.1 Ionizing Radiation

These are extremely high frequency electromagnetic waves which have enough photon energy to produce ionization by breaking the atomic bonds that hold the molecules in cells together and which can cause damages of genetic materials. The occurrence of ionization depends on the energy of the impinging individual particles or waves, and not on their numbers. Ionized molecules are unstable and quickly undergo chemical changes, which can lead to the formation of free radicals that can damage the molecules around it. DNA is sensitive to ionizing radiation and can lead to mutation in a cell's DNA. This could contribute to cancer or death of the cell. All cells in the body can be

damaged by ionizing radiation depending on the dosage (Ike, 2010). Examples are alpha, beta, gamma and x- rays. The evidence that small amounts of some types of ionizing radiation might confer a net health benefit in some situations is called radiation hormesis.

2.3.2 Non Ionizing Radiation

Non ionizing radiation (NIR) refers to any form of electromagnetic radiation that does not possess enough energy to remove an electron from the atoms or molecules it comes in contact with. Also refers to any type of electromagnetic radiation that does not carry enough energy per quantum (photon energy) to ionize atoms or molecules—that is, to completely remove an electron from an atom or molecule. Instead of producing charged ions when passing through matter, the electromagnetic radiation has sufficient energy only for excitation, the movement of an electron to a higher energy state They include radio waves, microwaves, infrared, visible light and the ultraviolet rays. Sources include GSM (Global System of Mobile Telecommunication) masts and phones, electrical high-tension wires, solar radiation etc. NIR has been linked with dielectric heating, where living tissues are heated by rotation of polar molecules induced by electromagnetic field. Also, research from Greece found a direct casual relationship between mobile phone radiation and DNA damage (Achudume *et al*, 2010).

A recent study showed that when people used a cell phone for 50 minutes, brain tissues on the same side of the head as the phone's antenna metabolized more glucose than did tissues on the opposite side of the brain. Inhabitants living near mobile phone base stations suffered from frequent headaches, memory changes, dizziness, tremors, depressive syndrome and sleep disturbance (Bevelaqua, 2015).

Both ionizing and non-ionizing radiation can be harmful to organisms and can result in changes to the natural environment. In general, ionizing radiation is far more harmful to

living organisms per unit of energy deposited than non-ionizing radiation. Ultraviolet radiation in some aspects occupies a middle ground, in having some features of both ionizing and non-ionizing radiation. Although nearly all of the ultraviolet spectrum of radiation is non-ionizing, at the same time ultraviolet radiation does far more damage to many molecules in biological systems than is accounted for by heating effects (an example is sunburn). These properties derive from ultraviolet's power to alter chemical bonds, even without having quite enough energy to ionize atoms.

The question of harm to biological systems due to low-power ionizing and non-ionizing radiation is not settled. Controversy continues about possible non-heating effects of low-power non-ionizing radiation, such as non-heating microwave and radio wave exposure. Non-ionizing radiation is usually considered to have no completely safe lower limit, although at some energy levels, new exposures do not add appreciably to background radiation (Jauchem, 2008).

2.3.2.1 Thermal Effects

The tissue temperature increase resulting from exposure to EMW is referred to as thermal effect. This effect may cause disruption of cell function and development (Bevelaqua, 2015). The increase of tissue temperature in an organ is related to imbalance between heat generation and heat dissipation. In contrast heat dissipation involves three mechanisms: heat conduction to other tissues, convection through blood perfusion, and radiation to the surroundings. The two most vulnerable organs to thermal effects are the eyes and testes because of limited capacity of heat dissipation .The thermal effect is the dominant established mechanism for biological and health effects associated to RF exposure (Al-Awadi *et al*, 2013).

2.3.2.2 Non-Thermal Effects

This occurs when the emitted energy of the RF field does not significantly increase the temperature of a cell, tissue or organism, but does bring to some physical or biochemical changes (Carl, 1969). For example there are several hypotheses that RF radiation can change cell membrane signal transduction. In Vitro research reports that membrane structure and functionality may be altered in RF fields (Media Advisory, 2012)

2.4 The Electromagnetic Spectrum

Electromagnetic (EM) radiation is transmitted in waves or particles at different wavelengths and frequencies. This broad range of wavelengths is known as the electromagnetic spectrum. The spectrum is generally divided into seven regions in order of decreasing wavelength and increasing energy and frequency. The common designations are radio waves, microwaves, infrared (IR), visible light, ultraviolet (UV), X-rays and gamma-rays. It can also be divided into two parts ionizing region and non ionizing regions. The non-ionizing portion of electromagnetic radiation consists of electromagnetic waves that are not energetic enough to detach electrons from atoms or molecules, ionizing them. These include radio waves, microwaves, infrared, and (sometimes) visible light. (Ultraviolet light, X-rays and gamma-rays are regarded as ionizing.) The occurrence of ionization depends on the energy of the individual particles or waves, and not on their number (Diem, 2005). An intense flood of particles or waves will not cause ionization if these particles or waves do not carry enough energy to be ionizing, unless they raise the temperature of a body to a point high enough to ionize small fractions of atoms or molecules by the process of thermal-ionization (this requires relatively extreme radiation energies, however). The electromagnetic spectrum is the range of all possible electromagnetic radiation frequencies. The electromagnetic

spectrum (usually just spectrum) of an object is the characteristic distribution of electromagnetic radiation emitted by, or absorbed by, that particular object.

2.4.1 Ultra Violet

Sources are Black light, Sunlight. Ultraviolet light covers wavelength from 100- 400nm can cause burns to skin and cataracts to the eyes (Thomas, 2009). Ultraviolet is classified into Near UV (280-100nm) which is absorbed by the atmosphere, medium UV (315-280nm) which interacts with skin DNA molecules and far UV (400-315nm) which is deeply penetrating (Manivannan, 2013). UV radiation above 10 eV (wavelength shorter than 125 nm) is considered ionizing. However, the rest of the UV spectrum from 3.1 eV (400 nm) to 10eV, although technically NIR, can produce photochemical reactions that are damaging to molecules by means other than simple heat. Since these reactions are often very similar to those caused by ionizing radiation, often the entire UV spectrum is considered to be equivalent to ionization radiation in its interaction with many systems (including biological systems). For example, ultraviolet light, even in the non ionizing range, can produce free radicals that induce cellular damage, and can be carcinogenic. Photochemistry such as pyrimidine dimer formation in DNA can happen through most of the UV band, including much of the band that is formally non ionizing. Ultraviolet light induces melanin production from melanocyte cells to cause sun tanning of skin. Vitamin D is produced on the skin by a radical reaction initiated by UV radiation. Plastic (polycarbonate) sunglasses generally absorb UV radiation. UV overexposure to the eyes causes snow blindness, which is a risk particularly on the sea or when there is snow on the ground.

2.4.2 Visible Light

Sources are operating theatre lights in the hospital, lasers and intense pulse height Light, or visible light, Sunlight, fire, LEDs and light bulbs. It has a very narrow range of

electromagnetic radiation of a wavelength that is visible to the human eye (about 400–700 nm), or up to 380–750 nm (Blettner *et al*, 2008). More broadly, physicists refer to light as electromagnetic radiation of all wavelengths, whether visible or not.

2.4.3 Infra Red

Infrared (IR) light is electromagnetic radiation with a wavelength between 0.7 and 300 micrometers, which equates to a frequency range between approximately 1 and 430 THz. IR wavelengths are longer than that of visible light, but shorter than that of terahertz radiation microwaves. Bright sunlight provides an irradiance of just over 1 kilowatt per square meter at sea level. Of this energy, 527 watts is infrared radiation, 445 watts is visible light, and 32 watts is ultraviolet radiation. Sources are Sunlight, thermal radiation, incandescent light bulbs, Lasers, remote controls. Infrared (IR) light is the part of the EM spectrum that people encounter most in everyday life, although much of it goes unnoticed. It is invisible to human eyes, but people can feel it as heat (Jim, 2015).

2.4.4 Microwave

Microwaves are electromagnetic waves with wavelengths ranging from as long as one meter to as short as one milli meter, or equivalently, with frequencies between 300 MHz (0.3 GHz) and 300 GHz. This broad definition includes both ultra high frequency (UHF) and extremely high frequency (EHF) (millimeter waves), and various sources use different boundaries (Andrea, 2007). Microwave Sources are radar, satellite communications, microwave ovens, airport millimeter scanners, motion detectors, long distance telecommunications, radar, WiFi.

2.4.5 Radio Waves

Radio waves are a type of electromagnetic radiation with wavelengths in the electromagnetic spectrum longer than infrared light. Like all other electromagnetic waves, they travel at the speed of light. Naturally occurring radio waves are made by lightning, or by astronomical objects (Diem *et al*, 2005). Artificially generated radio waves are used for fixed and mobile radio communication, broadcasting, radar and other navigation systems, satellite communication, computer networks and innumerable other applications. Different frequencies of radio waves have different propagation characteristics in the Earth's atmosphere; long waves may cover a part of the Earth very consistently, shorter waves can reflect off the ionosphere and travel around the world, and much shorter wavelengths bend or reflect very little and travel on a line of sight. Sources are radio masts, mobile phones, power lines, medical equipment, domestic and industrial equipment, television. AM and FM. Radio waves are a type of electromagnetic radiation with wavelengths in the electromagnetic spectrum longer than infrared light. Very low frequency (VLF) is the radio frequencies (RF) in the range of 3 to 30 kHz. Since there is no much bandwidth in this band of the radio spectrum, only the very simplest signals are used, such as for radio navigation. Also known as the myriameter band or myriameter wave as the wavelengths range from ten to one myriameter (an obsolete metric unit equal to 10 kilometers). Extremely low frequency (ELF) is the range of radiation frequencies from 300 Hz to 3 kHz (Blettner *et al*, 2008).

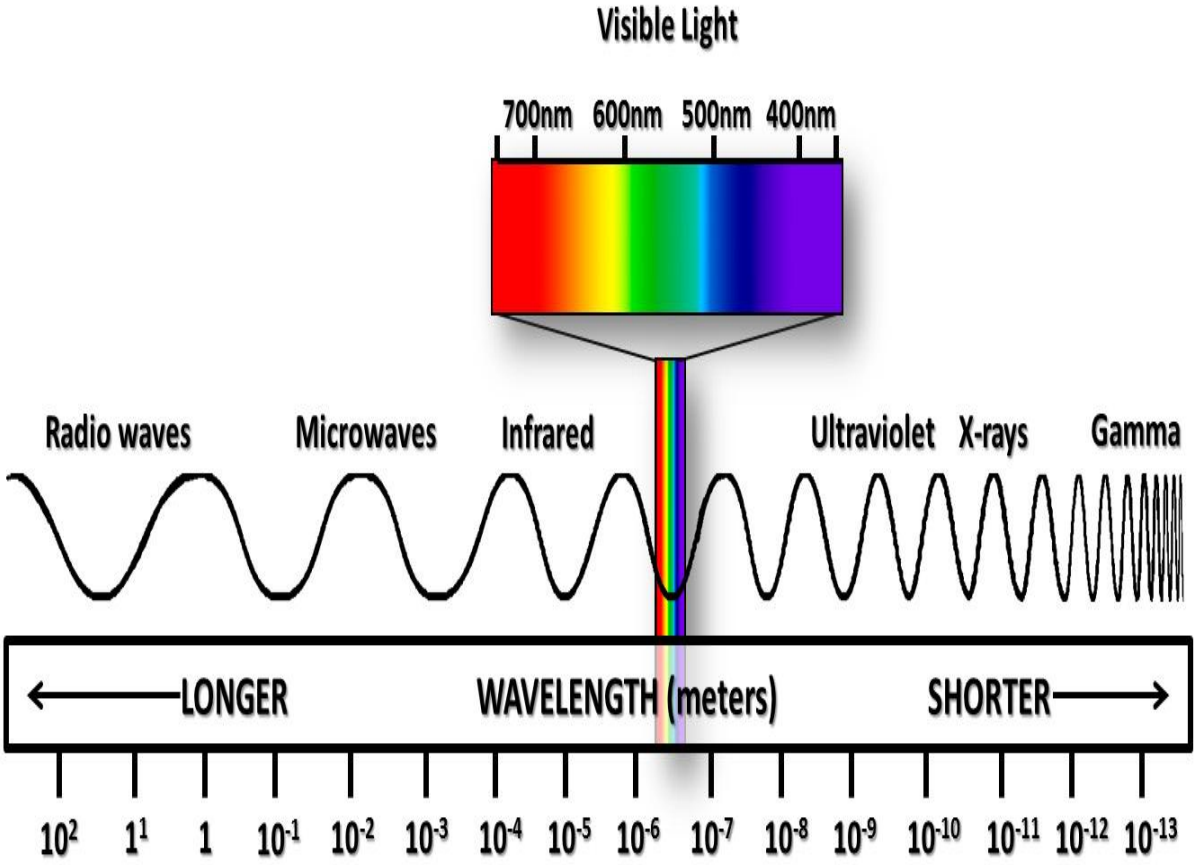


Figure 2. 2: **Electromagnetic Spectrum (Climate Science Investigation, 2016)**

2.4.5.1 Radio Wave Propagation

Radio waves are similar to light waves but they vary in several aspects. Radio waves do not always follow the inverse square law as their light wave counterpart. There are many external conditions that affect a radio wave such as atmospheric conditions. Discovery of radio signals as electromagnetic waves is attributed to Heinrich Hertz (Kyle, 2004). Before Hertz carried out various experiments the knowledge of induction fields among current carrying wires was used in the development of electric motors. In radio applications there is a radiated field that leaves the conductor and travels through space, antennas create a series of oscillation waves with specified frequencies and

wavelengths. The electromagnetic wave travels away from the antenna up to a distance where the energy is completely damped by the environment.

Radio signals are very much like light signals except that they have additional components of frequency. All radio waves are called transverse electromagnetic (TEM) waves because they consist of two fields, offset by 90 degrees along the propagating axis as shown in Fig. 2.2. The direction of the fields can be oriented by the transmitting antenna, thus antennas are therefore polarized. An antenna is classified as vertically or horizontally polarized based on the direction in which the electric field radiates from the antennas, most radio antennas are vertically polarized.

Radio waves are attenuated by the inverse square law, this is due to the energy being emitted from a point out into a spherical pattern. The power density of a radio wave is measured in watts per meter squared (W/m^2). Due to the inverse square law the power intensity at a distance d from the antenna can be described as in Equations (2.7) (isotropic conditions) where d is the distance from the antenna to the point of measurement (Kyle, 2004).

$$P_{distance} = \frac{P_{antenna}}{4\pi^2} \quad \text{(Kyle, 2004).} \quad (2.7)$$

d = diameter

The power delivered to the load (receiving antenna) is the product of the aperture gain and the transmitted power. Aperture gain is gain which is attributed to the antennas reflector if present.

$$P_{load} = \frac{P_{distance}\ \lambda^2}{(4\pi)^2\ d^2} \quad \text{(Kyle, 2004).} \quad (2.8)$$

Where λ = wavelength

Given the equations above the losses due to space propagation (dB) can be determined using

Loss (dB) = 10 Log $\left(\frac{P_{antenna}}{P_{load}}\right)$ (Kyle, 2004). (2.9)

2.4.5.2 Radio Wave Propagation on Earth

Transverse electromagnetic (TEM) waves do not rely on an atmosphere for travel, but they are affected by atmospheric conditions. Radio waves travel best through bands of atmosphere with low air densities. Thus waves that travel in the upper atmospheric layers are the waves that travel the furthest along the radio horizon. Air is less dense when it is cold, therefore waves travel the greatest distances at night. This is a common phenomenon with AM radio stations at night. It is much more likely to receive distant AM stations on a summer night than a winter day (Kyle, 2004).

High frequencies, those operating in the VHF and UHF bands, are very susceptible to multipath phenomena and line of sight reception. Thus radio communications operating in this range need to have a line of sight between the transmitter and receiver. Typically signal range in this band is within 100 miles of the antenna. Multipath phenomena is when a signal is distorted by the interaction with the genuine signal and a delayed signal which has been reflected upon its path. This phenomena results in a "ghost" image on the television, and causes cell phones to occasionally drop calls. Radio signals in the VHF and UHF bands are limited to line of sight from the antenna to the horizon. Refraction by the atmosphere can affect the magnetic fields so that the actual signal range is increased by unto 20 %.

When a signal enters into the atmosphere it interacts with the ions and as a result the signal is bent back in the direction of the ground. This ionization allows for the signal skip phenomenon. Waves are also affected by reflection and refraction. When a signal hits an object it is reflected at a complimentary angle, angle of reflection to the angle at which it hit the object, the angle of incidence. If a signal strikes an object it creates a

shadow zone behind it where radio communication is blocked. An example of this could be a lack of signal in a basement, or behind the moon (Kyle, 2004).

2.4.6. Maxwell's Equations

Electromagnetic waves were first predicted theoretically by the British Physicist James Clerk Maxwell in 1865. Maxwell's equations state that in order to create electromagnetic fields a time varying current source is needed. The fields must satisfy the four Maxwell's equations in a region containing time varying charge and current sources. Maxwell's equations in a lossless (dielectric), linear, isotropic, and homogeneous medium in time dependent form are stated below:

$$\nabla \cdot E = \frac{\rho}{\varepsilon} \tag{2.10}$$

$$\nabla \cdot \mathrm{B} = 0 \tag{2.11}$$

$$\nabla \times E = -\frac{\partial B}{\partial t} \tag{2.12}$$

$$\nabla \times B = u_o J + u_o \varepsilon \frac{\partial E}{\partial t} \tag{2.13}$$

For free space,

$$J = 0 \tag{2.14}$$

$$\rho = 0 \tag{2.15}$$

Thus Maxwell's equations become:

$$\nabla \cdot E = 0 \tag{2.16}$$

$$\nabla \cdot B = 0 \tag{2.17}$$

$$\nabla \times \boldsymbol{E} = -\frac{\partial B}{\partial t} \tag{2.18}$$

$$\boldsymbol{\nabla} \times \boldsymbol{B} = \mu_o \varepsilon_o \frac{\partial \boldsymbol{E}}{\partial t} \tag{2.19}$$

Taking the curl of equation (2.18),

$$\boldsymbol{\nabla} \times (\boldsymbol{\nabla} \times \boldsymbol{E}) = \nabla \times (-\frac{\partial \boldsymbol{B}}{\partial t}) \tag{2.20}$$

$$\boldsymbol{\nabla} \times (\boldsymbol{\nabla} \times \mathbf{E}) = -\frac{\partial(\boldsymbol{\nabla} \times \mathbf{B})}{\partial \mathrm{t}} \tag{2.21}$$

$$\boldsymbol{\nabla}(\boldsymbol{\nabla} \cdot \boldsymbol{E}) - \nabla^2 \boldsymbol{E} = -\frac{\partial(\boldsymbol{\nabla} \times \boldsymbol{B})}{\partial t} \tag{2.22}$$

Substitute (2.16) and (2.13) into (2.22)

$$-\nabla^2 \mathbf{E} = -\frac{\partial}{\partial t}(\mu_o \varepsilon_o \frac{\partial \boldsymbol{E}}{\partial t}) \tag{2.23}$$

$$\therefore \nabla^2 \mathbf{E} = \mu_o \varepsilon_o \frac{\partial^2 \boldsymbol{E}}{\partial t^2} \tag{2.24}$$

But for a progressive wave, the electric field component is given as:

$$\boldsymbol{E} = \boldsymbol{E}_o \sin \frac{2\pi}{\lambda}(ct - x) \tag{2.25}$$

$$\nabla^2 \boldsymbol{E} = \frac{\partial^2 \boldsymbol{E}}{\partial x^2} + \frac{\partial^2 \boldsymbol{E}}{\partial y^2} + \frac{\partial^2 \boldsymbol{E}}{\partial z^2} \tag{2.26}$$

$$\therefore \frac{d\boldsymbol{E}}{dx} = -\frac{2\pi}{\lambda} E_o \cos \frac{2\pi}{\lambda}(ct - x) \tag{2.27}$$

$$\frac{d^2 \boldsymbol{E}}{dx^2} = -\frac{4\pi^2}{\lambda^2} \boldsymbol{E}_o \sin \frac{2\pi}{\lambda}(ct - x) \tag{2.28}$$

$$\frac{d^2 \boldsymbol{E}}{dx^2} = -\frac{4\pi^2}{\lambda^2} \boldsymbol{E} \tag{2.29}$$

$$\therefore \boldsymbol{E} = -\frac{\lambda^2}{4\pi^2} \frac{d^2 \boldsymbol{E}}{dx^2} \tag{2.30}$$

Also,

$$\frac{d\boldsymbol{E}}{dt} = \frac{2\pi c}{\lambda} \boldsymbol{E}_o \cos \frac{2\pi}{\lambda}(ct - x) \tag{2.31}$$

$$\frac{d^2\boldsymbol{E}}{dt^2} = -\frac{4\pi^2c^2}{\lambda^2}\boldsymbol{E}_o \sin\frac{2\pi}{\lambda}(ct - x) \tag{2.32}$$

$$\therefore \frac{d^2\boldsymbol{E}}{dt^2} = -\frac{4\pi^2c^2}{\lambda^2}\boldsymbol{E} \tag{2.33}$$

$$\therefore \boldsymbol{E} = -\frac{\lambda^2}{4\pi^2c^2}\frac{d^2\boldsymbol{E}}{dt^2} \tag{2.34}$$

Equating (2.30) and (2.34)

$$-\frac{\lambda^2}{4\pi^2}\frac{d^2\boldsymbol{E}}{dx^2} = -\frac{\lambda^2}{4\pi^2c^2}\frac{d^2\boldsymbol{E}}{dt^2} \tag{2.35}$$

$$\therefore \frac{d^2\boldsymbol{E}}{dx^2} = \frac{1}{c^2}\frac{d^2\boldsymbol{E}}{dt^2} \tag{2.36}$$

Comparing equations (2.24) and (2.36)

$$\frac{1}{c^2}\frac{d^2\boldsymbol{E}}{dt^2} = \mu_o\varepsilon_o\frac{d^2\boldsymbol{E}}{dt^2} \tag{2.37}$$

$$\therefore \frac{1}{c^2} = \mu_o\varepsilon_o \tag{2.38}$$

Hence,

$$c = \frac{1}{\sqrt{\mu_o\varepsilon_o}} \tag{2.39}$$

Where $\mathbf{E} =$ electric field

J = current density

B = magnetic field

C = speed of light

$\mu_o = permeabilityoffreespace$

$\varepsilon_o = permitivityoffreespace$

ρ = charge density

2.5 Radiated Power Density

A GSM 900 base station antenna transmits in the frequency range of 935-960 MHz. This frequency band of 25 MHz is divided into 20 sub bands of 1.2 MHz which are allocated to various operators. There may be several carrier frequencies (1-5) allotted to one operator with upper limit of 6.2 MHz band width. Each carrier frequency may transmit 10 to 20 W of power. So, one operator may transmit 50 to 100 W of power and there may be 3-4 operators on the same roof top or tower, thereby total transmitted power may be 200 to 400 W. in addition directional antennas are used which typically has a gain of around 17db (numeric value is 50), so effectively, several KW of power may be transmitted in the main beam direction (Girish, 2010)

Power density P_d at a distance R is given by

$$P_d = \frac{\mathrm{P}.4\pi.\mathrm{f}^2}{\mathrm{C}_0^2.\mathrm{G_i}} \tag{2.40}$$

P = transmitted power

f= frequency

C_0 = speed of light and G_i = Antenna gain

The frequency from the antenna in the mast is related to the wave length by the relation

$$v = f\lambda \tag{2.41}$$

Where v =speed of light through which the signal travels, f =frequency of antenna and

λ =wavelength used in considering antenna type. This equation shows the relationship between frequency and wavelength such that as the frequency increases, the wavelength reduces (Ushie *et.al,* 2010). The amount of RF absorbed by the body is measured using a dosimetric quantity called Specific Absorption Rate (SAR) which is given as

$$= \frac{\sigma}{\rho} E^2 \qquad (2.42)$$

Where S= Specific absorption rate in W/kg, σ=Conductivity, ρ= Density and

E=Electric field strength in V/m.

2.6 Biological Effect of Microwave and Radiofrequency Radiation

When a human body is exposed to electromagnetic radiation, it absorbs radiation, because human body consist of 70% liquid. It is similar to that of cooking in the microwave oven where the water in the food content is heated first. Microwave absorption effect is much more significant by the body parts which contain more fluid (water, blood, etc), like the brain which consist of about 90% water. Effect is more pronounced where the movement of the fluid is less, for example, eyes, brain, joints, heart, abdomen, etc. also human height is much greater than the wavelength of the cell tower transmitting frequencies, so there will be multiple resonances in the body. This results in boils, drying up of the fluids around eyes brain, joints, heart, abdomen, etc. (Girish, 2010).The biological effects of electromagnetic radiation probably begin with the organism acting like a radio antenna. The pulsed radiofrequency (RF) radiation generates eddy currents flowing through it and (in the case of cell cultures) also through the surrounding medium. When they impinge on the delicate membranes that surround its individual cells, they disturb their ionic structure and destabilize them. The same is true of the membranes that divide cells into their various internal compartments and organelles. The human body makes a good antenna since blood vessels, which have low resistance pathways filled with a highly conductive salty fluid, connect virtually all of its parts. Even cell membranes, which have a high resistance to direct current (DC) allow radio-frequencies through because of their high capacitance (Andrew, 2008).

There are several health hazards associated with telecommunication masts. Some of these are described in the following sub sections.

2.6.1 Effect on Cell Membrane Ca^{2+}

Electromagnetic radiation that is far too weak to cause significant heating can nevertheless remove calcium ions from cell membranes (Blettner *et al*, 2008). Later, Carl Blackman showed that this occurs only with weak pulsating radiofrequency RF radiation because they allow more time for dislodged calcium ions to diffuse clear of the cell membrane and be replaced by different ions, before the field reverses. Pulses are more effective than smooth sine waves because their rapid rise and fall times catapult the ions quickly away from the membrane and leave even more time for them to be replaced by different ions before the field reverses (Andrew, 2008).This is probably why the pulsed radiation from mobile phones can be particularly damaging.

Free calcium ions normally occur in calcium salts but, like other positive ions, they can also bind to the negatively charged membranes of living cells. These membrane-bound ions are in chemical equilibrium with the corresponding free ions in the surrounding medium, but there is a disproportionately large amount of calcium because it has two positive charges (i.e. it is divalent), which attracts it more strongly to the negative membrane (Blackman *et al*, 2008). Most of the other readily available ions in living cells (e.g. potassium) have only one charge (i.e. they are monovalent).

However, the extra charges on the divalent ions such as calcium and magnesium let weak alternating electromagnetic fields remove them selectively from the membrane, which can have dire metabolic consequences (Blackman *et al*, 2009). Positive ions strengthen cell membranes because they help bind together the negatively - charged phospholipid molecules that form a large part of their structure.

Calcium ions are particularly good at this because their double positive charge enables them to bind more strongly to the surrounding negative phospholipids and hold them together like cement. However, monovalent ions are less able to do this(Ha, 2005).Therefore, when electromagnetic radiation replaces calcium with monovalent ions, it weakens the membrane and makes it more likely to tear and form pores, especially under the stresses and strains imposed by the moving cell contents (Melikov *et al*, 2001). Normally, small pores in phospholipid membranes are self-healing but, while they remain open, the membrane will have a greater tendency to leak. Membrane leakage can explain almost all of the adverse effects of electromagnetic radiation, including those from mobile phones and their base stations.

2.6.2 Effect on DNA

Lai and Singh (1996) were the first to show effect of pulsed RF radiation in cultured rat brain cells, and it has since been confirmed by many other researchers. They found that pulsed RF - radiation like that from mobile phone base station antenna and GSM handsets caused both single and double stranded breaks in the DNA of cultured human and animal cells. Not all cell types were equally affected and some, such as lymphocytes, seemed not to be affected at all (Diem *et al*, 2005).

However, in susceptible cells, the degree of damage depended on the duration of the exposure. With human fibroblasts, it reached a maximum at around 16 hours. Because of the very high stability of DNA molecules, they are unlikely to be damaged directly by weak radiation. The most plausible mechanism is that DNase (an enzyme that destroys DNA), and possibly other digestive enzymes, were leaking through the membranes of lysosomes (organelles that digest waste) that had been damaged by the radiation. If so, there is also likely to be considerable collateral damage to other cellular systems. If similar DNA fragmentation were to occur in the whole organism, we would

expect a reduction in male fertility from damage to the DNA of developing sperm, an increased risk of cancer from DNA damage in other cells (this may take many years to appear) and genetic mutations that will appear in future generations. Microwave radiation can also interfare with the natural processes involved in DNA replication and repair by subtly altering molecular conformation (architecture). Another possibility of DNA damage is via free radical formation inside cells. Free radicals kill cell by damaging macromolecules such as DNA, protein and membrane and are shown to be carcinogenic. Several reports have indicated that electromagnetic frequency (EMF) from telecommunication masts enhance free radical activities in cells (Diem *et al,* 2005). The Fenton reaction is a catalytic process of iron to convert hydrogen peroxide, a product of oxidative respiration in mitochondria into hydroxyl free radical which is a very potent and toxic free radical. Thus EMF affects the DNA via an indirect secondary process. Damage to DNA is a central mechanism for developing tumors and cancer. When the rate of damage to DNA exceeds the rate at which DNA can be repaired, there is the possibility of retaining mutations and initiating cancer. DNA damage in brain cells can affect neurological functions and also possibly lead to neurodegenerative diseases.

2.6.3 Blood Brain Barrier

The brain is protected by tight junctions between adjacent cells of capillary walls by the blood brain barrier (BBB), which selectively lets nutrients pass through from the blood to the brain but keeps toxic substances out. Experiments conducted on young laboratory rats found that RF from mobile phones can significantly open the BBB in animals and cause leakage of albumin from blood vessels in inappropriate locations (neurons and glial cells surrounding the capillaries) in the brain (Girish, 2010). The presence of albumin in brain tissue is a sign that blood vessels have been damaged and that the brain

has lost some of its protection. A closer look at the cells within the brain also revealed that exposed animals had scattered and grouped dark neurons often shrunken with loss of internal cell structures. Neuronal damage of this kind may not have immediate consequence but in the long run, it may result in reduced brain reserve capacity that might be unveiled by other later neuronal diseases. It must be noted that the BBB and neurons are the same in a rat and a human being.

In another research, a single two-hour exposure to a cell phone just once during its lifetime permanently damaged the BBB and, on autopsy50 days later, was found to have damaged or destroyed up to 2% of an animal's brain cells, including cells in areas of the brain concerned with learning, memory and movement. (Girish, 2010).

2.6.4 Irreversible Infertility.

It might be expected that DNA damage in the cells of the germ line to result in a loss of fertility. Several studies have shown significant reductions in sperm motility, viability and quantity in men residing close to phones mast (Agarwal *et al*, 2006). So it is advisable for men to keep their mobile calls to a minimum. The effects of phone mast use on female fertility are not yet known since the eggs are formed in the unborn fetus and it will have to be waiting until the child reaches puberty to see the full effects of the mother's mobile phone use. So far, similar investigations have not been performed with the radiation from mobile phone base stations, but it cannot be assume that they are necessarily safe just because they are further away. Radiation levels, even hundreds of meters from the mast, can still give biological effects and living near one will involve a considerably longer exposure than from just making the occasional phone call (Agarwal *et al*, 2007). Study shows that men who made lengthy calls have fewer rapidly motile sperm.

2.6.5 Autism

Autism refers to a disorder of neural development characterized by impaired social interaction and communication, and by restricted and repetitive behaviour. There has been a 6000 percent increase in autism in recent years, which corresponds in time to the proliferation of mobile telecommunications, Wifi and microwave ovens. This can also be explain in terms of electromagnetically-induced membrane leakage leading to brain hyperactivity. Just after its birth, a child's brain is essentially a blank canvas, and it goes through an intense period of learning to become aware of the significance of all of its new sensory inputs, e.g. to recognize its mother's face, her expressions and eventually other people and their relationship to him(Hawley and Gunner, 2009). During this process, the neurons in the brain make countless new connections, the patterns of which store what the child has learnt. However, after a matter of months, connections that are rarely used are pruned automatically so that those that remain are hard-wired into the child's psyche (Huttenlocher *et al*, 2007). The electromagnetic production of spurious action potentials during this period will generate frequent random connections, which will also not be pruned, even though they may not make sense. It may be significant that autistic children tend to have slightly larger heads, possibly to accommodate unpruned neurons (Hill and Frith, 2006).

2.6.6 Risk to Children and Pregnant Women

Children are more vulnerable to radiation from telecommunication base stations as they absorb more energy than adults owing to their smaller head and brain size, thinner cranial bones and skin, thinner more elastic ears, lower blood cell volume, as well as greater conductivity of nerve cells and the energy penetrates more deeply. Tumours in the mid brain are more deadly than in the temporal lobe. Also children's cells reproduce more quickly than adults. Their immune system is also not as well developed as adults

hence are less effective against fighting cancer growth. Children have longer lifetime exposure. The younger the child the deeper the penetration due to their thinner skull. For these reasons it is critical that children under the age of 16 use cell phones only for short essential calls as they have more danger of getting brain tumors. Brain tumors have taken over leukaemia as the biggest cause of death among children. Due to these reasons countries like Belgium, France, Finland, Germany, Russia and Israel have publicly discouraged the use of cell phones by children (Girish, 2010).

A pregnant woman and the foetus both are vulnerable because of the fact that these RF radiations continuously react with the developing embryo and increasing cells. Microwave radiation can damage the placental barrier, the membrane which prevents the passage of some materials between the maternal and foetal blood, protecting the foetus, implying that a pregnant woman should avoid staying close to a telecomm mast, avoid use of cell or use during emergency only (Girish, 2010).

2.6.7 Effect on Electromagnetic Property of Human Cell

Human Body contains electrolytes and ions, which are positively or negatively charged, the water molecule is a polar molecule - it has positive and negative charges separated by a dipole length (Victor, 2007). Being made up of approximately 15-70% water, electrolytes and ions, it follows that the human body has its own weak electromagnetic field and each of the cells has its own EM Field too. It follows that strong and even weak Electromagnetic Fields emitted from any electrical or electronic equipment will interact with and affect the human body's own weak electromagnetic fields, and, therefore, interfere with the body's natural healing processes. It has been established from the dangers of EMF's that biological systems have the property of storing electromagnetic oscillations and incorrect oscillations can also occur (i.e. not endogenous - not originating within the body), or be introduced through the

environment, which stubbornly remain in the organism and lead to incorrect regulation which is known from biochemistry that can lead to illness and diseases(Victor, 2007). In other words it establishes that human health depends on balance being maintained in cell's electromagnetic field, that the cells store information in the form of electromagnetic oscillations (information within our DNA for e.g. is 'electronically' stored in this way) and information from incorrect or non-endogenous oscillations (not of the body - EMF's/ELF's being typical examples) can be stored within the cells energy fields leading to disturbance, disorder and incoherence (loss of equilibrium - balance) which can lead to genetic damage, damage to our DNA, illness and disease. In other words, our own electromagnetic frequencies essential to our health, the repair, reproduction and replication of DNA can be altered by storing, or 'taking on board' information (oscillations) from outside sources of energy such as electromagnetic and electrical radiation. All biochemical processes are activated and regulated by our body's own electromagnetic fields. The fact that magnetic fields enter our body's own energy fields is well documented by biophysicists and can easily be measured. Electromagnetic frequencies which are man-made are unnatural, chaotic and disordered and biophysics has established that 'Every kind of frequency combination which is not in order produces disease.' According to Schauberger, disease occurs through a disturbance of the electromagnetic field in the cells: they become disordered and incoherent (Steve, 2016).

The effects upon human health by exposure to EMF Radiation, looking from a biochemical point if viewed, would appear to show ill health is caused by the displacement of electrolytes/ions within the body and by interfering with the body's natural way of communicating (neurological system) and maintaining homeostasis– balance. This will weaken the defence mechanism of the body as the body expends

energy attempting to redress this imbalance. If we cannot get away from these EMF fields because we live within their field of influence, the body will be unable to correct this electrical and biochemical imbalance and, as the science of Biophysics has proven that we only become ill when the defense mechanism of the body is weakened, it follows that we will undoubtedly become ill as a direct result of living or working within these EMR fields (Victor, 2007). So it is not a question of whether these EMF fields cause health problems or not, that is not in doubt. What is uncertain is just how this ill-health will manifest in an individual; this is determined by the individual's own constitution and health and may manifest in many ways, which is why we are seeing so many 'new' immune deficient disorders today. What is certain, through even the most basic understanding of physics is that EMF's do weaken our energy fields and this will lead to some form of illness and disease in humans (Andrew, 2008). Children, in particular, with their developing immune systems and ill or sick people are more prone to the effects of EM Radiation, and are, therefore, at risk the most (Eltiti *et al*, 2007)

2.6.8 Effect on Birds

EM radiation from telecommunication masts affects birds, bees, animals, plants and the environment. it is very rare to see a bee, sparrow, pigeon or any bird flying near and staying near the telecommunication mast. The reason is that the surface layer of birds is relatively larger than their weight in comparison to human body so they absorb more radiation. Since fluid content is small due to less weight, it gets heated up very fast (Girish, 2010). When birds are exposed to weak EMFs, they disorient and begin to fly in all directions, which explains migratory birds undermining navigational abilities. A large number of birds like pigeons, sparrows, swans are getting lost due to interference from the new unseen enemy ie the mobile phone mast. Several million birds of 230 species die each year from collisions with telecommunication masts during migration in

the United States. Accidents happen mainly in the night in the fog or bad weather, when birds might be using the earth's magnetic field (MF) for navigation and could be seriously disoriented by the microwave radiation from telecommunication mast(Kavokin, 2008).

2.6.9 Effect on Plants

Apart from bees, birds and animals, electromagnetic radiation emanating from cell towers can also affect vegetables, crops and plants in its vicinity. Studies show that this type of radiation can choke seeds, inhibit germination and seed growth thereby affecting the overall growth of agricultural crops and plants. A reduction in wheat and corn yield in the fields near high EMF lines has also been reported (Girish, 2010).

2.6.10 Interference with other Gadgets like Pace Maker

Radiation from telecommunication mast interfare with navigational equipment. The use of cell phones is banned in airborne flights. This electromagnetic interference can cause malfunctioning of life-line electronic gadgets in the hospitals thereby potentially endangering patients. It is advisable to restrict mobile phone use in clinical areas like operating theatres and intensive care units. RF exposure from cellular phone base antennas and mobile phones can also affect patients carrying pacemaker, implantable cardiovascular Defibrillators (ICDs) and Impulse Generators. The signals generated cause electromagnetic interference with the device and interfare with its proper functioning (Girish, 2010).

2.6.11 Heat-Shock Proteins

They can be produced directly in response to electromagnetic radiation at levels millions of times lower than those that generate significant heat (Blank and Goodman, 2010). The job of these heat-shock proteins is to combine with vital enzymes, putting

them into a sort of cocoon that protects them from damage. However, this also stops them working properly, so it isn't an ideal solution. It is worth noting that it is at night time that the body carries out most of its 'healing work' as it constantly works to restore homeostasis (Victor, 2007). As these phone Masts are fixed structures, it is, therefore, impossible for an individual to avoid these man-made chaotic energies from interfering with their energy fields and the body's natural ability to restore homeostasis. Therefore, people are being denied their unquestionable right to have and to hold onto good health. If the body is constantly being subjected to EM stress from these Masts, especially at night time, the body cannot repair itself adequately as it is constantly expending energy elsewhere trying to deal with these unbalanced microwaves and the body gradually becomes depleted of excess energy and its energy stores are reduced, weakening the defense mechanism of the body (Victor, 2007).

2.7 RF Exposure Guidelines

With the current massive deployment of GSM systems in Nigeria, it is only prudent that the country's regulatory agencies take steps similar to those of their counterparts in other countries to mitigate the potential hazards of RF radiation from installed BTS. A number of countries have developed and/or adopted national or international guidelines for checking and ensuring that emissions from installed wireless communication systems conform to EMF safety levels. The adopted guidelines specify the Maximum Permissible Exposure (MPE) limits of EMF or RF energy that may be allowed into the environment for the general public. The International Commission for Non-Ionizing Radiation Protection (ICNIRP) standards and guidelines are widely used for setting national standards to restrict human bodies to EMF exposure (LEAC, 2010). Exposure standards usually refer to electric and magnetic component or power density limits. They are individually measured when it is required by the field properties related to the

field regions. Nigeria, through an act of its National Assembly, is poised to adopt the ICNIRP standard. Table 2.1 shows some countries and the guidelines they have adopted.

Table 2. 1: Countries and Guidelines

Country	**MPE standard**	**Country**	**MPE Standard**
Argentina	ICNIRP	Taiwan	ICNIRP
Cote d' Ivoire	ICNIRP	Singapore	FCC, ICNIRP
Brazil	ICNIRP and WHO	Pakistan	ICNIRP
Hong kong	ICNIRP FCC	United kingdom	ICNIRP
Canada	ICNIRP, IEEE	D. Republic	IEC/CENELEC
Mexico	IEC/CEN ELEC	United State	FCC, IEEE

(Ekata, 2015)

The ICNIRP guidelines include the basic restrictions that are established for EMF-induced current density in the body and the reference levels established for the strength of EMF external to the body (Stam, 2011). Because the basic restrictions are difficult to measure, the more restrictive reference level is used to determine compliance with the basic restrictions and emission limits.

The ICNIRP reference levels for occupational and the general public exposures for the frequencies of interest are shown in Table 2.2

Table 2. 2: National and International Guidelines Exposure levels to GSM and TETRA

Body	**Exposure Limits in W/m^2**		
	GSM		**TETRA**
	900 MHz	**1800 MHz**	**1400 MHz**
NRPB (UK)	33.0	100.0	26.0
ICNIRP	4.5	9.0	2.0
IEEE (USA)	6.0	12.0	2.7
EU Countries (ICNIRP)	4.5	9.0	2.0

(Girish, 2010).

In order to protect the population living around base stations and users of mobile phones, governments and regulatory bodies adopt safety standards. The Institute of Electrical and Electronic Engineers (IEEE) standards specified for general public is a safe distance of approximately 4.35m from the antenna (IEEE, 1999).

Girish (2010) in his work mentioned that the Bio-Initiative Report in 2007 (610 pages long) has been prepared by a group of independent scientists after thorough and very careful survey of the literature and they concluded that the existing standards for public safety are inadequate to protect public health and proposed 1000μW/m^2 for outdoor, cumulative RF exposure. Some of the proposed maximum exposure values through various reports were given below:

•Building Biology Institute, Germany, provided following guidelines for exposure:

a. less than 0.1 μW/m^2 - no concern

b. 0.1 - 10 μW/m^2 - slight concern

c.10 - 1000 μW/m^2 - severe concern

d. Above 1000 μW/m^2 - extreme concern

•H Thomas *et al* in Germany reported that power densities should not exceed 100 μW/m^2 (Girish, 2010).

•EU Parliament (STOA 2001) recommends - 100 $\mu W/m^2$

According to Federal Communication Commission standard (FCC) standards, the safe level of specific absorption rate (SAR) for the general public is 1.6W/kg in 1g of tissue.

2.8 Review of Previous Works

Several research work has been carried out regarding the assessment of RF power density of telecommunication base stations in different parts of the world and their findings are as follow;

Jagbir and Dhami (2012) carried out an orientation studies of a cell phone mast to access electromagnetic radiation (EMR) exposure level in Delta state and came up with the findings that there are maximum and minimum exposure zones around a cell phone mast and also described how power density changes with distance for different antenna with the peak power density observed at a distance of 40m for most antenna orientations.

Bolaji and Idowu (2012) reported that low level exposure from mobile phone base stations are usually less than most international guidelines.

In 2012, Victor *et al* carried out a research on the assessment of RF radiation exposure levels from selected mobile base station in Lokoja and came up with the finding that the RF exposure hazard index was below the permitted RF exposure limit to the general public recommended by ICRNIP (Victor *et al*, 2012).

Battrenas and Bukus (2011) carried out a study on indoor measurements of the power density close to mobile station antenna Vilnius, Lithuania and observed that the values obtained were well below the maximum permissible exposure (MPE) limits. During measurement indoor the maximum power density levels from antenna, never exceeded

the reference level 10 μW/cm² stipulated in the HN 81:2005 guidelines that are in act in our country. Power density was in the range 0 μW/cm² − to 9.03 μW/cm².

Ibitoye *et al* (2011) conducted a study to determine power density around different telecommunication antenna base stations in Lagos state and to compare the measured values with the international recommended rules. They utilized a highly sensitive device (radiofrequency meter, electrosmog etc.) capable of measuring distances of about 200m from the selected antenna base station in Lagos state. In the result obtained, power density of the studied base station varied between 0.219 and 302.40mW/m^2. Comparison of the results with the ICNIRP and IEEE/ANSI recommended safe standards of 1200mW/m^2 and 5700mW /m^2 shows that the measured values are not likely capable of inducing significant health effect among people that are at least 6m away from the antenna.

In a similar study conducted by Elliott *et al* (2010) to investigate the risk of early childhood cancers associated with the mothers exposure to radiofrequency radiation from macro cell mobile phone base station (mast) during pregnancy. 1397 cases of cancer in children aged 0-4 years from national cancer registry 1999-2001 and 5588 birth controls from national birth register was used as the participant. The result of the study shows that the mean distance of registered address at birth from a macro cell base station based on a national database of 76,890 base station antenna in 1996-2001, was similar for cases and control (1107(SD1131) mv 1073(SD1130) m, p = 0.31), as was total power output of base stations within 700m of the address (2.89(SD 21.7) kw v 3.00(SD 6.0) kw P = 0.54) and modeled power density(-30.3(SD21.7) dBm v – 29.7 (SD 21.5) dBm, P = 0.41). For the modeled power density at the address at birth, compared with the lowest exposure category the adjusted odds ratios were 1.01(95% confidence interval 0.87 to 1.18) in the intermediate and 1.02 (0.88 to 1.20) in the

highest exposure category for all cancers (P = 0.79 for trend), 0.97 (0.69 to 1.37) and 0.76(0.51 to 1.21), respectively, for brain and central nervous system cancers (P = 0.33 for trend), and 1.16 (0.90 to 1.48) and 1.03 (0.79 to 1.34) for leukemia and non-Hodgkin's lymphoma (P = 0.51 for trend).

Thomas *et al*(2009) in a study, presented data related to GSM (Global System for Mobile Communications) cellular phone radiation resulting from antenna sites and towers inside residential areas in Germany. A statistical evaluation of over 200 representative high frequency field measurements from 2001-2002 is presented. Measurements were conducted at different distances and directions using a frequency selective spectrum analysis to obtain only GSM power densities following the Swiss guideline for GSM cellular phone radiation measurements. Derived from this data, GSM cellular phone tower radiation is dominant in comparison to FM radio or TV emissions. The median power density was found to be in the range of 200 $\mu W/m^2$ with the maximum level exceeding 100,000 $\mu W/m^2$. A total of 25 percent of the power densities exceeds 1,000 $\mu W/m^2$, which has been suggested to be the average threshold value for non-thermal biological effects. Two of the most important factors are the distance and the direct line of sight to the antenna site. At the typical residential cell tower distance of about 250 m in cities, with direct line of sight, the observed levels are in the range of 200 $\mu W/m^2$. The results show that, especially for future cellular Universal Mobile Telecommunications System (UMTS) applications, there are several options to minimize additional HF radiation exposures to the population and reduce the potential risk for harmful exposures.

Blettner *et al* (2008) carried out a work on ''mobile phone base station and adverse health effects'' with the aim of investigating the relationship between proximity to mobile phone base station and health complains. A population based, multi-phase,

cross-sectional study was conducted in which 30,047 persons from a total of 51,444 participants answered questions on how mobile phone base station affect their health. The result shows that of the 30,047 participants, 18.7% of the participants were concerned about the adverse health effects of mobile base station while an additional 10.3% attributed their adverse health effect to the exposure from them. Participants living within the vicinity of a mobile phone base station (500m) reported slightly more health complaints than others.

Jauchem (2008) carried out a review of the epidemiological medical and scientific studies from mid-1998 through early 2006 dealing with possible effects of radiofrequency energy (RFE) on humans relating to cardiovascular, reproductive and immune system. The result of the study shows both positive and negative findings, in a majority of instances significant health effect were reported. There were major effects on some cardiovascular parameters such as lower 24hrs heart rate, blunted circadian rhythm of heart rate in laboratory studies of volunteers exposed to cell phone RFE. In a population-based study of wide range of RFE frequencies, findings were equivocal for effects on birth defects, fertility, neuroblastoma in offspring and reproductive hormones. Some changes in immunoglobulin levels and in peripheral blood lymphocytes were reported in different studies. Due to variation in result and difficulties in comparing presumably exposed subject with control, however, it is difficult to propose a unifying hypothesis of immune-system effects. Although subjective symptoms may be produced in some sensitive individual exposed to RF, there were no straight forward differences in such symptoms between exposed and control subjects in very few epidemiological and laboratory studies.

Kwan – hoong(2004) carried out a work similar to that conducted by Blettner *et al* on ‘’ Radiation, Mobile Phones, Base stations and Health’’ with an aim to explain the mode

of operation of telecommunication antennas and the radiation associated with it. He however, attributed the radiation exposure to be predominantly determined by the following parameters; distance to the antenna site, line of sight to the antenna site, type of the antennas, number, power, and orientation of the antennas, capacity of the antenna site (number of channels / frequencies), vertical distance between location and antenna site, type of building construction / type of window glass and total reflection of the environment.

Ronni *et al* (2004) conducted a study titled "increased incidence of cancer near a cell phone transmitter station" in which they examined a town that locates within 350 meter radius of a cell tower and was studied over time, and measuring the numbers of cancers reported. Participants are people (n = 622) living in the area near a cell-phone transmitter station for 3-7 years who were patients of one health clinic. The exposure began 1 year before the start of the study when the station first came into service. A second cohort of individuals (n = 1222) who get their medical services in a clinic located nearby with very closely matched, environment, workplace and occupational characteristics was used for comparison. The findings were then compared to the cancer rate of the whole country. The researchers made an exerted effort to form unbiased conclusions. As stated in their own words above, they found "a significantly greater incidence" of lung carcinoma, breast carcinoma, Hodgkin's disease, ovary carcinoma and on and on within the population of the town. This means there is good reason to believe that cell towers are hazardous to human health.

Santini *et al* (2002) conducted a study and reported some symptoms like fatigue, irritability, headache and nausea, observed in the study population living within 100m - 300 m of a base station.

The central role of calcium in controlling the 'tightness' of these layers was latter supported by another research conducted by Chu *et al* (2001) on respiratory epithelia (which also have tight junctions). They found that either low levels of external calcium or the addition of ethylene glycol tetracetic acid EGTA (a substance that removes calcium ions from surfaces) caused massive increases in its electrical conductance (a measure of its permeability to ions) and to its permeability to much larger virus particles.

Persson *et al*(1997) carried out a research on 'Blood-brain barrier permeability in rats exposed to electromagnetic fields used in wireless communication' and discovered that radiation from telecommunication antennas can cause an increase in the permeability of blood brain barrier, even to protein molecules as large as albumin and this can damage the neurons beneath. The loss in 'tightness' of the blood-brain barrier could be due to an increase in membrane leakage and/or to a disruption of the tight junctions themselves. Either of these could be triggered by an electromagnetically-induced loss of calcium.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Materials

- Tape meter for distance measurement
- Global Positioning System (GPS) receiver
- A handheld spectrum analyzer 2658A model B and K Precision
- Pointing stick

3.2 Methodology

3.2.1 Study Area

The study was carried out in three local government areas, namely; Zaria, Sabon Gari and Giwa Local Governments Areas respectively. The areas lies between latitude $11^0$28'02.61" North and longitude $7^0$43'21.72" East as shown in Figure 3.1. The three Local Government Areas were selected for easy accessibility and in order to reduce cost.

Table 3. 1: Description of the study area

CODE	LOCATION	SITE NO.	LATTITUDE	LONGINTUDE	NEAREST BTS (approx. distance)	SPECIAL FEATURES
B1	Demonstration Secondary Sch, A.B.U. Zaria	100094	11.15392	7.655532	5m	6 sectoral antenna. Inside school
B2	A.B.U.Gymnasium	Zar 027	11.15421	7.644562	500m	6 sectoral antenna.Inside school
B3	Faculty of Vet. Medicine A.B.U. Zaria	_	11.15679	7.647890	None	6 sectoral antenna.Inside school
B4	Jama'a, Zango	_	11.14155	7.672427	100m	6 sectoral antenna. Close to a block factory
B5	Jama'a, Zango	T5759	11.14012	7.671437	100m	6 sectoral antenna.Around residential area.
B6	Hayin malam	B2332	11.13763	7.673165	300 m	6 sectoral antenna. Around residential area.
B7	Kwarbai, Zaria city	Zar 003	11.06875	7.707837	60 m	6 sectoral antenna.Beside a residence.
B8	Lemu, Zaria city	_	11.06841	7.708597	5m	6 sectoral antenna.Around residential area.
B9	Milgoma, shika	_	11.17960	7.605235	100 m	6 sectoral antenna.Around residential area
B10	Milgoma, shika	Zar 018	11.18167	7.603047	100 m	6 sectoral antenna.Around residential area.
B11	Giwa	_	11.23398	7.507448	20 m	6 sectoral antenna.close to residential area.
B12	Giwa	_	11.25259	7.468438	300 m	6 sectoral antenna. Beside local government secretariat.
B13	Hayin madara	Gw001	11.25247	7.468477	None	6 sectoral antenna.Around residential area.
B14	Tashar gundu	B6096	11.24223	7.489063	None	6 sectoral antenna. Along express road.
B15	Mararrabar yakawada.	NC000148	11.27442	7.422795	None	6 sectoral antenna. Along express road.

(Umar, 2016)

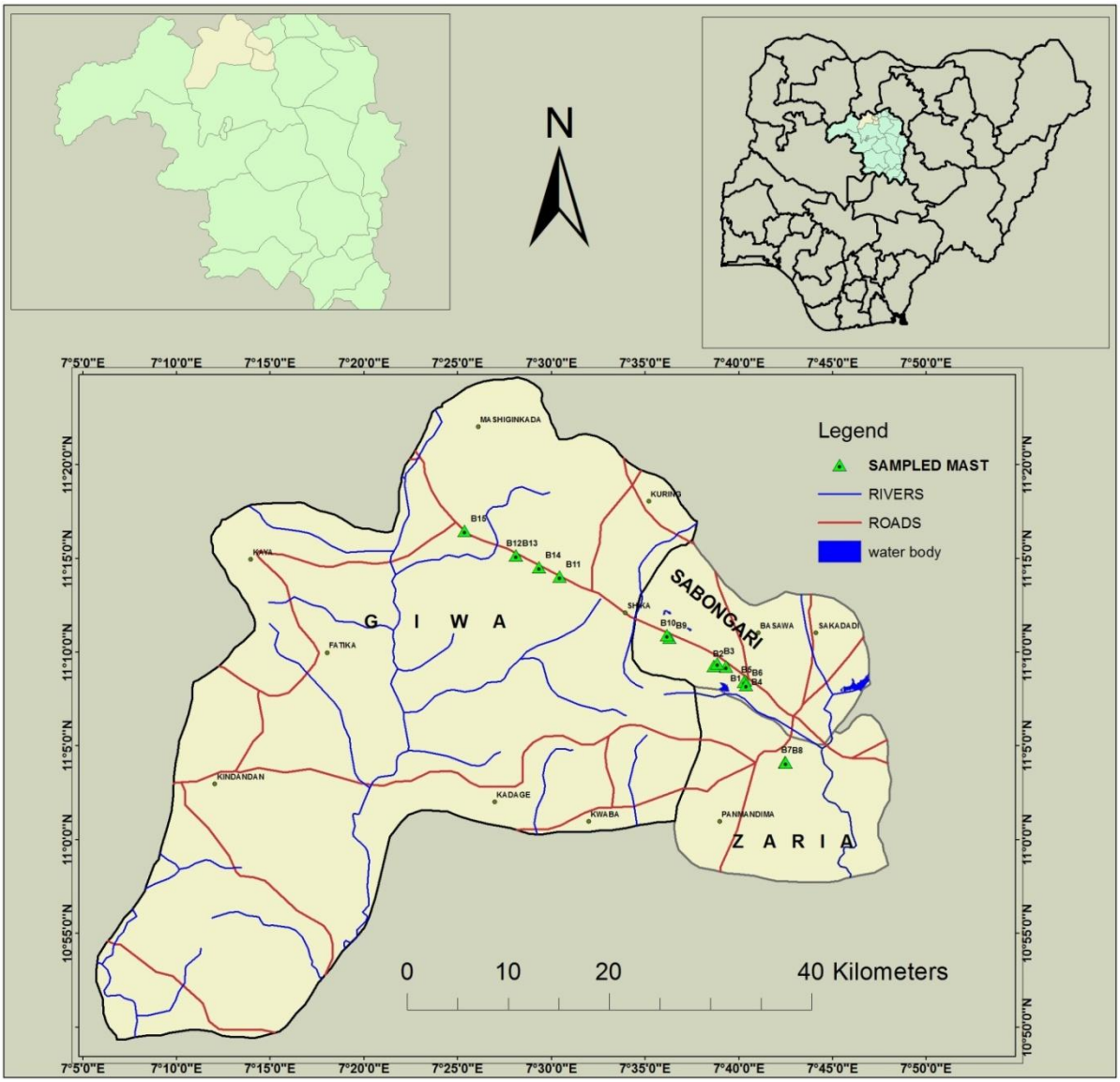


Figure 3. 1: Map of the study area

Source: Adapted and Modified From Zaria Urban Map

3.2.2 Data collection

A total of 15 base stations were selected at random, covering about 4 network providers: Globacom, MTN, Etisalat and Airtel. These were selected according to their proximity to buildings, number of antennas mounted on their masts, how close they are to other base stations and the population density around them. The mobile base stations were coded B1 to B15 as shown in table 3.1. B1 to B13 were assessed based on human population living close to the BTS, vegetation and other masts in line of sight. B14 and B15 consisted of base stations in open areas along the high way where buildings are far located.

Most of the base stations have at least 3 sectoral antennas and each antenna covers 120^0 radius, which means that they cover 360^0 sector area. Measurements were taken in a convenient direction around the base station at every 20 m interval for 100 m radius from the foot of each telecommunication mast. A total of 67 measurements were made, 5 samples each from 13 base stations and 2 samples from the remaining 2 base stations. Measurements were taken using spectrum analyzer (Model 2658A) B and K Precision capable of measuring received radiated power in decibel relative milli-watts (dBm). Each of the measurements was made by holding the spectrum analyser away from the body and at about 1.5 m above the ground level with the meter pointing towards any sector of the antenna. The measured power densities fluctuated and thus, measured values were recorded only about 5 minutes after the meter value was stable.

On getting to the site, a quick environmental assessment was carried out by using the density of houses around, vegetation and the visibility of any other mast in line of sight. The proximity of residential buildings to base stations is the reason for choosing this range of distance.

However, the received signal powers detected by the measuring instrument at various distances are the received radiated powers with respect to distances from the transmitting tower.

Power density P_d at a distance R is calculated using equation 3.1 (Girish, 2010):

$$P_d = \frac{P \times 4\pi \times f^2}{C^2 \times G} \qquad 3.1$$

where,

P = Measured power in Watts, G = 2.14 (Gain of receiving antenna), f = frequency in Hz, C_0 = Velocity of light.

Power received by an antenna at a distance R is calculated using equations 3.2 and 3.3

$$P_r = \frac{P \times G \times Area}{4\pi R^2} \ (Wm^{-2}) \qquad 3.2$$

$$\text{Power received} = \text{power density} \times \text{Area} \qquad 3.3$$

The measured radiated power is in decibel relative milli-watts (dBm) where as international standards are in terms of power density (Wm^{-2}).Therefore, Power in decibel relative milli-watts (dBm) is converted to watts using equation 3.4

$$P\ (\text{watt}) = \frac{P(dBm)}{1000} \ \text{watt} \qquad 3.4$$

Where P (dBm) = power in decibel relative milli-watts.



Plate 3.1: Power density measurement using spectrum analyser 2658A model



Plate 3. 2: Measurement from the foot of the antenna inside the BTS behind Faculty of Veterinary Medicine, Ahmadu Bello University.

3.3.3 Data Analysis

Quantitative data collection method of random sampling was used to select the base transceiver stations analysed. Data used in this study involved both primary and secondary data. The secondary data were collected from records of the ICNIRP recommended guidelines while the primary data was collected through field measurement. The data collected were used to calculate power density from the selected mobile base stations using equation 3.1 which was used to check if the exposure levels in these areas are low and as such not able to produce significant health risks among the people living in these areas.

3.4 Instrumentation

3.4.1 Spectrum Analyser

A handheld Compact and lightweight 1.8 kg spectrum analyzer 2658A model was used for the measurement of the power density of electromagnetic radiation from the selected mobile base stations. The meter is a broad band device for monitoring high frequency radiation in the range of 50 kHz to 8.5 GHz covering most of the wireless communication frequency spectrum. It can be used to measure Channel power, occupied bandwidth, Electric field strength, Magnetic field strength and Frequency. It has three-axis (isotropic) measurement mode with adjustable threshold and 200 point manual memory function. It is extremely sensitive. It has an average noise level of -127 dBm at 1GHz which provides a wide dynamic range with a display scale of 100 dB/10div (at 10 dB/div) in the amplitude axis. The spectrum analyser has a USB device for PC connectivity and 5.7 inches, 640×480 color LCD display. Figures 3.4 and 3.5 show a typical spectrum analyser.



Plate 3.3: Spectrum analyzer 2658A



Plate 3. 4: Spectrum analyser 2658A showing power mode

3.4.2 Principle of operation

The spectrum analyzer is a form of radio receiver with a display at the output indicating the output level. The analyser display, like that of an oscilloscope has two axes, the vertical level or amplitude and the horizontal level. The vertical axis is normally on a logarithmic scale to enable signals over a much wider range to be seen on the spectrum analyser. Typically a value of 10 dB per division is used. This scale is normally calibrated in dBm (decibels relative 1 milliwatt) and therefore it is possible to see absolute power levels as well as comparing the difference in levels between two signals. The horizontal scale conversely is normally linear and it can be adjusted to cover the required range (Ian, 2016).

As the scan moves along the horizontal axis, the display shows the level of any signals at that particular frequency. The receiver is tuned or scanned over the required range and the filters are chosen to accept the required signal bandwidth. The spectrum analyser uses the superheterodyne principle used in many radio receivers as the underlying principle on which its operation depends. The superheterodyne principle uses a mixer and in addition to a locally generated or local oscillator to translate the frequency. The signal entering the front end is translated to another frequency, typically lower in frequency. Using a fixed frequency filter in the intermediate frequency section of the equipment enables high performance filters to be used, and the analyzer or receiver input frequency can be changed by altering the frequency of the local oscillator signal entering the mixer (Ian, 2016).

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Results

The result of power density in nanowatts per square metre (nWm^{-2}) obtained at different distances for 13 base transceiver stations (BTS) are presented in Table 4.1.The value of the maximum power density was found to be 58.08 nWm^{-2} observed at 80 m from an Etisalat BTS (location B9) while the minimum power density was found to be 9.29 nWm^{-2} observed at 100 m from an Airtel BTS (location B7).The maximum power density of 58.08 nWm^{-2} obtained is below the ICNIRP maximum permissible limit of 4.7 Wm^{-2} for GSM 900 as indicated in Table 2.2. In order to have a clearer picture of the power density distribution over all locations, the average of the power density over the entire locations at an interval of 20 m from the foot of each base station up to 100 m was obtained as presented in Table 4.3.The average value of power densities over all locations (B1 to B13) and over all distance intervals from the base stations was found to be 23.52 nWm^{-2} which is below the ICNIRP maximum permissible limit of 4.7 Wm^{-2}

Table 4. 1: Power density at different distances

	Power density (nWm^{-2})				
Code	**20m**	**40m**	**60m**	**80m**	**100m**
B1	19.77	19.23	19.68	18.66	19.91
B2	21.23	20.28	20.28	22.08	18.62
B3	20.23	21.04	20.65	20.37	20.80
B4	44.26	45.60	44.77	12.33	11.59
B5	15.67	9.40	12.53	13.99	12.05
B6	11.80	10.67	12.13	11.17	10.47
B7	11.72	10.42	10.38	11.19	9.29
B8	11.27	10.64	10.21	9.95	9.86
B9	10.96	51.99	51.40	58.08	47.86
B10	26.06	20.28	21.33	20.32	23.82
B11	33.72	33.50	33.50	33.65	33.57
B12	34.68	34.51	34.36	34.20	34.04
B13	34.59	34.44	34.36	34.20	33.42

Table 4.2 : Power density at 1600 m away from the transmitting antenna for B14 and B15

Code	**Power density(fWm^{-2})**	**Distance (m)**	**Signal**
B14	345.90	1600	None
B15	346.70	1600	None

Table 4.2 represents the power density observed at 1.6 km away from the BTS in open area along Zaria - Funtua express road where buildings are far located. It was observed that there was no network signal at 1.6 km away from the mast. The power density values were very small and far below the ICNIRP maximum permissible limit of 4.5 Wm^{-2}.

For each interval of 20 m, the average power density for all locations is presented in Table 4.3.

Table 4. 3: Average power density within 100 m radius for all locations B1 to B13

Code	Average power density (nWm^{-2})
B1	19.45 ± 0.51
B2	20.50 ± 1.30
B3	20.62 ± 0.32
B4	31.71 ± 18.04
B5	12.73 ± 2.34
B6	11.25 ± 0.71
B7	10.60 ± 0.92
B8	10.39 ± 0.58
B9	44.06 ± 18.86
B10	22.36 ± 2.52
B11	33.59 ± 0.10
B12	34.36 ± 0.25
B13	34.20 ± 0.46

Table 4.4 to 4.16 represent the power received (Radiation) by the human body living or passing within the mobile BTS of locations B1 to B13 at different distances from the foot of the antenna, the area of the human body as an object measured in metre square(m^2) was considered. The radiation level absorbed by the body is calculated by multiplying the power density at a particular distance by the possible human area at that point as shown in equation 3.3. The average human surface area considered were 1.9 m^2 for adult men, 1.6 m^2 for adult women, 1.33 m^2 for children (12 – 13 years), 1.14 m^2 for children (10 years), 1.07 $m^2$for child of about 9 years of age and 0.5 m^2 for a child of 2 year old. The body surface area is calculated using Mosteller formula simplified as

$$\text{Body surface area} = \frac{\sqrt{weight\ (kg) \times height(cm)}}{3600} \qquad \text{(Mosteller, 1987)} \qquad 4.1$$

Table 4. 4: Radiation level from B1

	Power density at difference distances (nWm^{-2})				
	20m	**40m**	**60m**	**80m**	**100m**
Body Surface Area (m^2)	**19.77**	**19.23**	**19.68**	**18.67**	**19.91**
1.9	37.56	36.54	37.39	35.46	37.82
1.6	31.63	30.77	31.49	29.86	31.85
1.33	26.29	25.58	26.17	24.82	26.48
1.14	22.54	21.92	22.43	21.28	22.69
1.07	21.15	20.58	21.06	19.97	21.30
0.5	9.89	9.62	9.84	9.33	9.96

Table 4. 5: Radiation level from B2

	Power density at difference distances (nWm^{-2})				
	20m	**40m**	**60m**	**80m**	**100m**
Body Surface Area (m^2)	**21.23**	**20.28**	**20.28**	**22.08**	**18.62**
1.9	40.34	38.53	38.53	41.95	35.38
1.6	33.97	32.44	32.44	35.33	29.79
1.33	28.24	26.97	26.97	29.37	24.77
1.14	24.20	23.12	23.12	25.17	21.23
1.07	22.72	21.70	21.70	23.63	19.92
0.5	10.62	10.14	10.14	11.04	9.31

Table 4. 6: Radiation level from B3

	Power density at difference distances (nWm^{-2})				
	20m	**40m**	**60m**	**80m**	**100m**
Body Surface Area (m^2)	**20.23**	**21.04**	**20.66**	**20.37**	**20.80**
1.9	38.44	39.98	39.24	38.70	39.51
1.6	32.37	33.67	33.05	32.59	33.28
1.33	26.90	27.98	27.47	27.09	27.66
1.14	23.06	23.98	23.55	23.22	23.71
1.07	21.65	22.51	22.10	21.80	22.25
0.5	10.11	10.52	10.33	10.19	10.40

Table 4. 7: Radiation level from B4

	Power density at difference distances (nWm^{-2})				
	20m	**40m**	**60m**	**80m**	**100m**
Body Surface Area (m^2)	**44.26**	**45.60**	**44.77**	**12.33**	**11.59**
1.9	84.092	86.64	85.07	23.43	22.012
1.6	70.81	72.97	71.63	19.73	18.54
1.33	58.86	60.65	59.55	16.40	15.41
1.14	50.46	51.99	51.04	14.06	13.21
1.07	47.36	48.80	47.91	13.19	12.40
0.5	22.13	22.80	22.36	6.17	5.80

Table 4. 8: Radiation level from B5

	Power density at difference distances (nWm^{-2})				
	20m	**40m**	**60m**	**80m**	**100m**
Body Surface Area (m^2)	**15.68**	**9.40**	**12.53**	**13.99**	**12.05**
1.9	29.77	17.85	23.81	26.59	22.90
1.6	25.07	15.04	20.05	22.39	19.28
1.33	20.84	12.50	16.67	18.61	16.03
1.14	17.86	10.71	14.29	15.96	13.74
1.07	16.76	10.06	13.41	14.98	12.90
0.5	7.83	4.70	6.27	6.10	6.03

Table 4. 9: Radiation level from B6

	Power density at difference distances (nWm^{-2})				
	20m	**40m**	**60m**	**80m**	**100m**
Body Surface Area (m^2)	**11.80**	**10.67**	**12.14**	**11.17**	**10.47**
1.9	22.43	20.27	23.05	21.22	19.90
1.6	18.892	17.07	19.41	17.87	16.75
1.33	15.70	14.19	16.14	14.85	13.93
1.14	13.46	12.16	13.83	12.73	11.94
1.07	12.63	11.41	12.98	11.95	11.20
0.5	5.90	5.33	6.067	5.58	5.24

Table 4. 10: Radiation level from B7

	Power density at difference distances (nWm^{-2})				
	20m	**40m**	**60m**	**80m**	**100m**
Body Surface Area (m^2)	**11.72**	**10.42**	**10.38**	**11.19**	**9.29**
1.9	22.27	19.80	19.71	21.27	17.65
1.6	18.76	16.68	16.60	17.91	14.86
1.33	15.59	13.86	13.80	14.89	12.36
1.14	13.36	11.89	11.83	12.77	10.59
1.07	12.54	11.15	11.10	11.98	9.94
0.5	5.86	5.21	5.19	5.60	4.64

Table 4. 11: Radiation level from B8

	Power density at difference distances (nWm^{-2})				
	20m	**40m**	**60m**	**80m**	**100m**
Body Surface Area (m^2)	**11.27**	**10.64**	**10.21**	**9.95**	**9.86**
1.9	21.42	20.22	19.40	18.91	18.74
1.6	18.04	17.03	16.34	15.93	15.78
1.33	15.00	14.15	13.58	13.24	13.12
1.14	12.86	12.13	11.64	11.35	11.24
1.07	12.064	11.39	10.92	10.65	10.55
0.5	5.64	5.32	5.10	4.98	4.93

Table 4. 12: Radiation level from B9

	Power density at difference distances (nWm^{-2})				
	20m	**40m**	**60m**	**80m**	**100m**
Body Surface Area (m^2)	**10.96**	**51.99**	**51.40**	**58.08**	**47.87**
1.9	20.83	98.80	97.67	110.35	90.94
1.6	17.54	83.206	82.25	92.92	76.58
1.33	14.58	69.16	68.37	77.24	63.66
1.14	12.50	59.26	58.60	66.21	54.56
1.07	11.73	55.64	55.00	62.14	51.21
0.5	5.48	26.00	25.70	29.04	23.93

Table 4. 13: Radiation level from B10

	Power density at difference distances (nWm^{-2})				
	20m	**40m**	**60m**	**80m**	**100m**
Body Surface Area (m^2)	**26.06**	**20.28**	**21.33**	**20.32**	**23.82**
1.9	49.52	38.5	40.53	38.61	45.26
1.6	41.70	32.44	34.13	32.52	38.11
1.33	34.67	26.97	28.373	27.03	31.68
1.14	29.71	23.12	24.32	23.17	27.16
1.07	27.891	21.70	22.82	21.75	25.49
0.5	13.03	10.1	10.67	10.16	11.91

Table 4. 14: Radiation level from B11

	Power density at difference distances (nWm^{-2})				
	20m	**40m**	**60m**	**80m**	**100m**
Body Surface Area (m^2)	**33.72**	**33.50**	**33.50**	**33.65**	**33.57**
1.9	64.07	63.64	63.64	63.94	63.79
1.6	53.95	53.59	53.59	53.84	53.72
1.33	44.85	44.56	44.55	44.76	44.65
1.14	38.44	38.19	38.19	38.36	38.27
1.07	36.08	35.84	35.84	36.018	35.92
0.5	16.86	16.75	16.75	16.83	16.79

Table 4. 15: Radiation level from B12

	Power density at difference distances (nWm^{-2})				
	20m	**40m**	**60m**	**80m**	**100m**
Body Surface Area (m^2)	**34.68**	**34.51**	**34.36**	**34.20**	**34.04**
1.9	65.88	65.58	65.28	64.981	64.68
1.6	55.48	55.22	54.97	54.72	54.47
1.33	46.12	45.90	45.70	45.49	45.27
1.14	39.53	39.35	39.17	38.99	38.81
1.07	37.10	36.93	36.76	36.59	36.42
0.5	17.34	17.26	17.18	17.10	17.02

Table 4. 16: Radiation level from B13

	Power density at difference distances (nWm^{-2})				
	20m	**40m**	**60m**	**80m**	**100m**
Body Surface Area (m^2)	**34.60**	**34.43**	**34.36**	**34.20**	**33.42**
1.9	65.73	65.43	65.28	64.98	63.50
1.6	55.35	55.10	54.97	54.72	53.47
1.33	46.01	45.80	45.67	45.48	44.45
1.14	39.44	39.26	39.17	38.99	38.10
1.07	37.02	36.85	36.76	36.60	35.76
0.5	17.30	17.22	17.18	17.10	16.71

Table 4. 17: Average Absorbed Radiation Level

	20m	**40m**	**60m**	**80m**	**100m**
Body Surface Area (m^2)	**Average Power density at difference distances**				
	22.77	**24.77**	**25.04**	**23.09**	**21.95**
1.9	43.26	47.06	47.58	43.88	41.69
1.6	36.43	39.63	40.07	36.95	35.11
1.33	30.28	39.63	33.31	30.71	29.19
1.14	25.95	32.94	28.55	26.33	25.02
1.07	24.36	28.24	26.79	24.71	23.48
0.5	11.38	12.38	12.52	11.55	10.97

4.2 Discussion

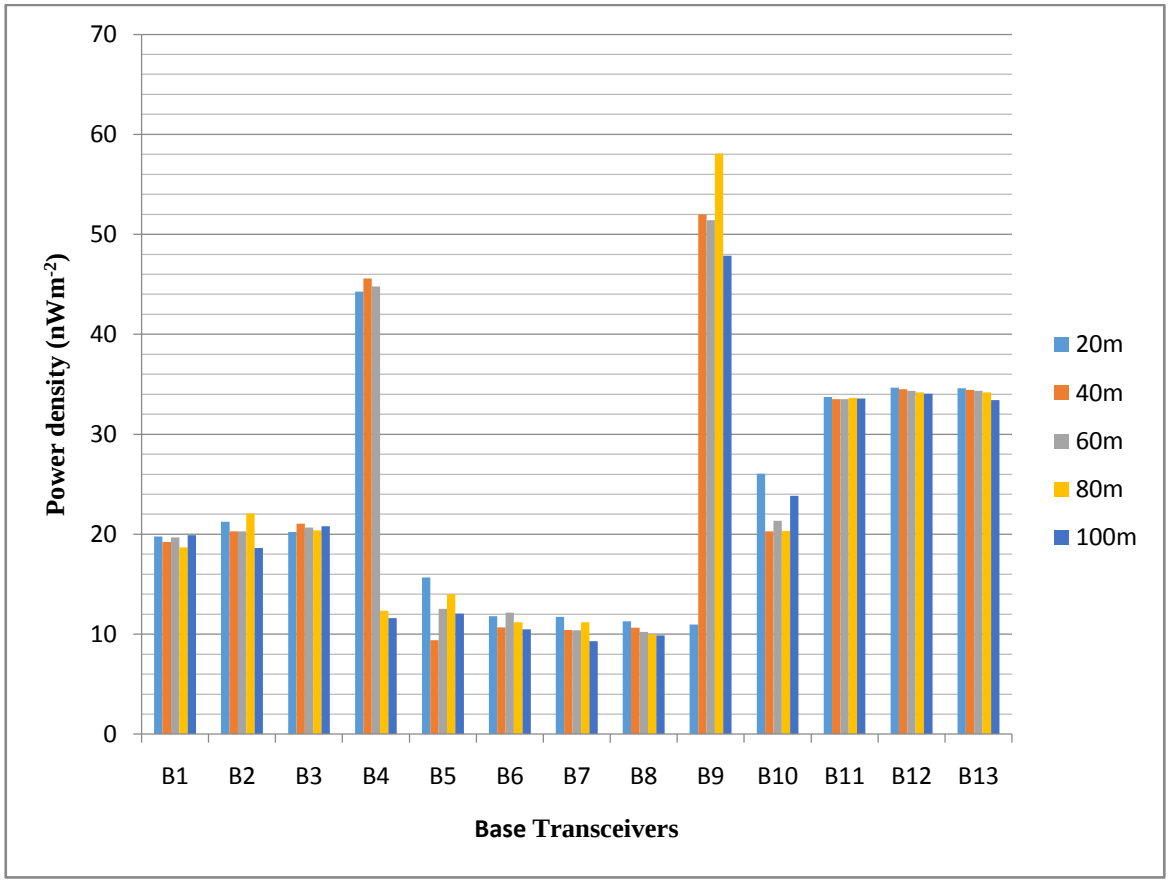


Figure 4. 1: Power density at different distances for all locations

The results obtained from the graph above showed that the maximum level of RF which an individual can be exposed to is 58.08 nWm^{-2}, this value was obtained at a distance of 80m from the base station of location B9. This high value can be due to the presence of other high powered mobile BTS clustered around the location.

The presence of trees and buildings reduced the RF measurements taken in location B1 especially the low level of RF observed at 20 m distance from the foot of the antenna this is because trees and building walls obstruct a portion of the external wireless radiation. Hence, similar patterns were observed for measurements made for both locations B3 and location B9 due to reflection and absorption by residential buildings,

obstruction by trees and radiation penetration through windows and the number of calls by passersby (Anonymous, 2016).

The power density decreases as the distance increases for most masts obeying the inverse square law. The fluctuations in the readings obtained were mainly due to interference from nearby and distant masts. The measured power density deviated from the inverse square law at some locations, because of reflection, scatter and refraction from the ground, windows, and attenuation by trees and buildings. Radio waves are refracted the same way as light waves. On a hot day the surface of the ground can be heated and this causes air to rise. Hot air and the colder air have slightly different values of refractive index and this causes the wave to bend. Also, the distance between two masts is another factor considered; this is due to the fact that each antenna is linked with the other antenna via a line- of- sight communication link and thus, the RF field from one antenna influences the measurements made from the other antenna. For an area within a radius of 100 m and which is characterized by clusters of base stations, RF energy tends to concentrate more at some points than the others.

It was observed that in most residential areas, the base stations are closely located and usually have 6 sectoral antennas. Some base stations were found to be within 100 m radius of a reference base station; the RF emissions of antennas of such base station were shielded by buildings. It is expected that base stations with 6 or more sectoral antennas would have high RF emission but the reverse is the case. The reason is that the RF signal level around a base station at any instant depends on the number of simultaneous calls handled by that base station and the caller's position relative to the base station. Thus, when there is high call rate at a base station there would be more RF

emission. Therefore mobile BTS with small number of Sectoral antennas will emit more radiation than those with higher number of sector antennas.

In order to have a clearer picture of the power density distribution over all locations, the average of the power densities over the entire locations at an interval of 20 m from the foot of each base station up to 100 m was obtained as presented in Table 4.4 and illustrated by Figure 4.2.The average value of the power densities was estimated by adding up all the measured values and the total was divided by the total number of outcome.

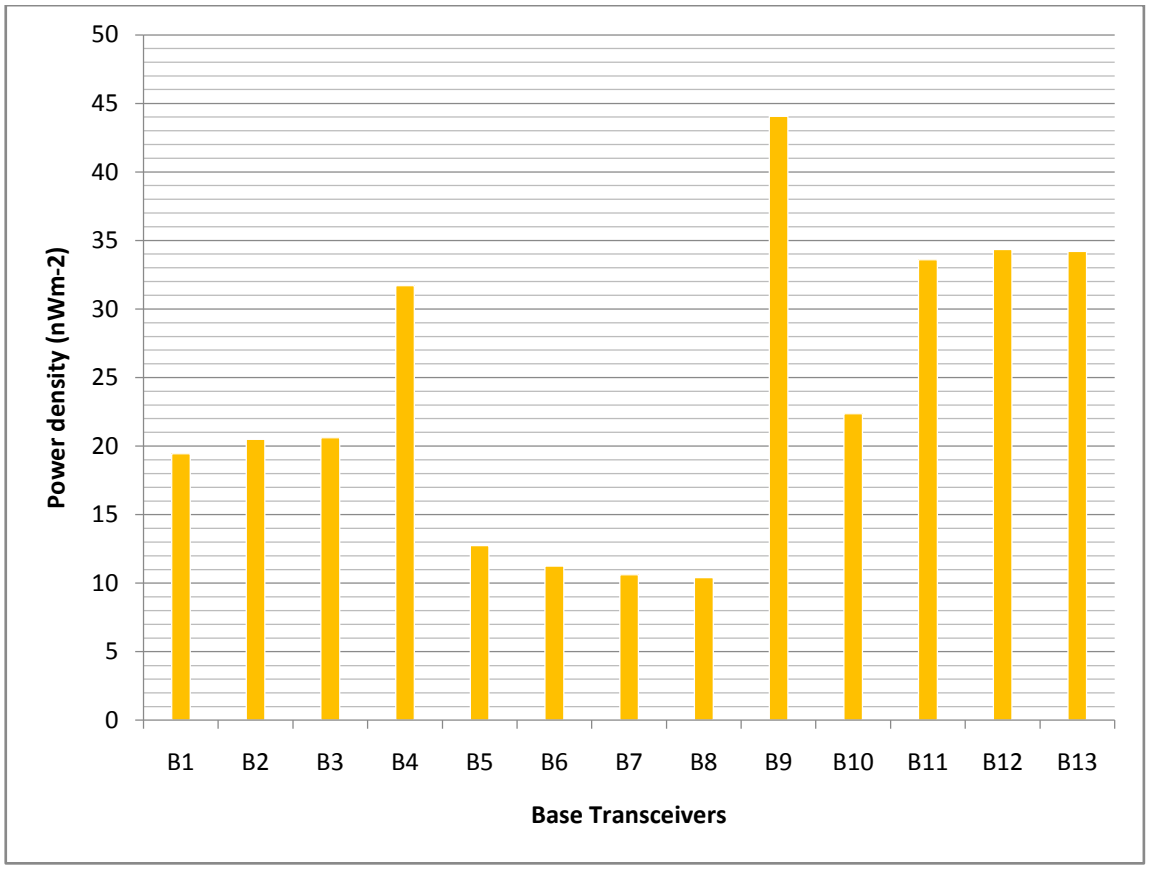


Figure 4. 2: Average power density at 20 m interval for locations B1 to B13

In far field conditions, it is expected that the variation of the power density with distance obeys the inverse-square-law. However it was observed that some of the calculated power densities deviated from the inverse square law. This may be due to

interference from nearby masts and phone calls being made by the passers-by and residents within the vicinity of the base station.

Highest average power density was observed at location B9 at 44.06 nWm^{-2} while the lowest power density value was observed at location B8 at 10.39 nWm^{-2}.

The absorbed radiated power by human body at different distances is presented in figure 4.3

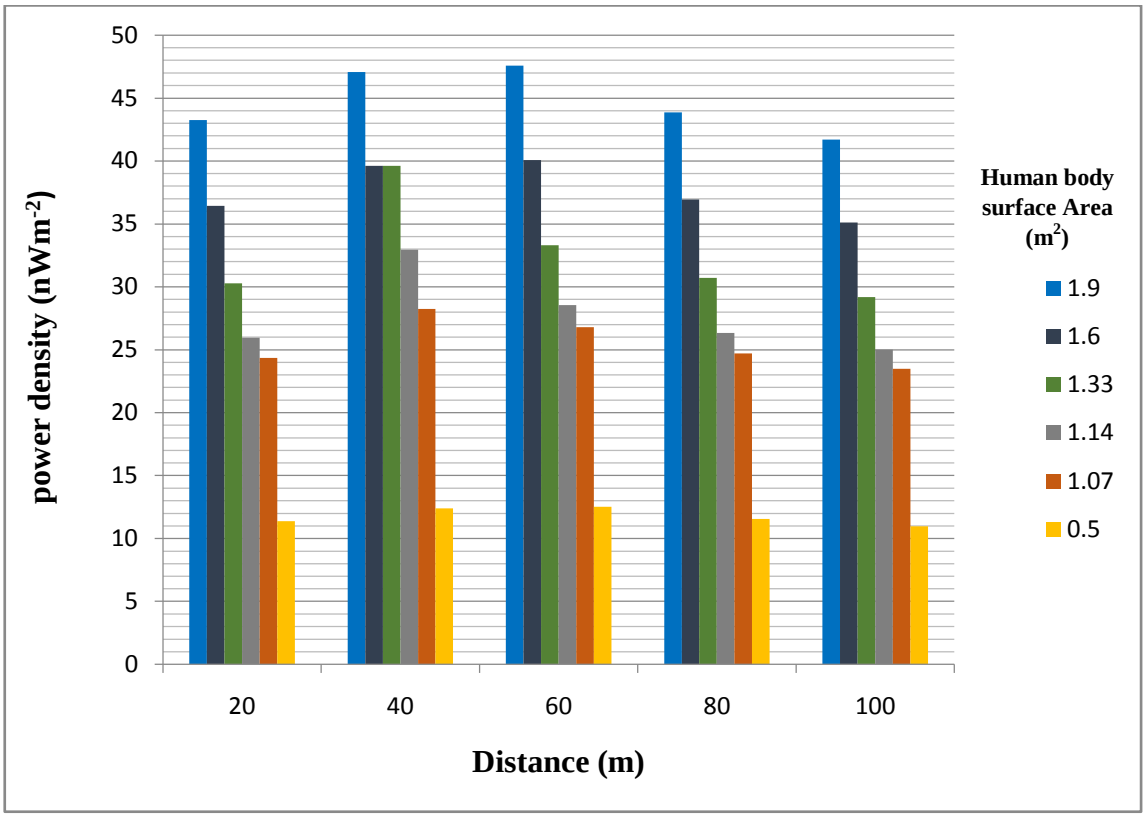


Figure 4. 3: Absorbed radiated power by human body at different distances.

It is observed from the graph that adults received more radiation than the children; the absorbed radiation level in adults is about twice that of the children. This is due to the fact that adults have a larger body surface area than the children. For a 2 year old child of surface area 0.5 m^2, the radiation received is half that of the adults.

- Although the ICNIRP set maximum limits for RF exposure, it does not take into consideration long term effects of RF exposure and non thermal effects of RF exposure.
- For example considering Table 4.12, the maximum radiated power received by an adult male living or passing around the BTS in one second was 110.35 nWs^{-1}.

- In one hour the received radiation will be $110.35 nWs^{-1} \times 3600 = 397.26\ \mu Ws^{-1}$.
- In one day it will be $397.26\ \mu Ws^{-1} \times 24$ hours $= 9.53.05\ mWs^{-1}$ and
- In one year it will be $9.53.05\ mWs^{-1} \times 365$ days $= 3.5\ Ws^{-1}$ of RF radiation received.

According to research $3.5\ Ws^{-1}$ can cause electroencephalogram (EEG) alteration in humans, sleep disorders, weakness, fatigue, pain and child leukaemia (Girish, 2010).

Majority of the selected BTS were located very close to residential or official building. Some were within 3.5 m radius from the foot of the antenna to residential buildings which fail to comply with the safety limits of 4.35m as suggested by the Institute of Electrical Electronics Engineers (IEEE, 1999).

CHAPTER FIVE

CONCLUSION, SUMMARY AND RECOMMENDATION

5.1 Conclusion

The level of the maximum power density was found to be 58.08 nWm^{-2} and it was obtained at a distance of 80 m from the base station of location B9. The average power density over all locations was evaluated to be 23.52 nWm^{-2} .

The maximum power density as well as its average value is by far less than the maximum level of 4.5 Watt m^{-2} for GSM system. Therefore, radio frequency emissions from the selected serving BTS do not exceed the maximum permissible exposure limits.

The distance from the BTS is a major factor that determines the level of radiation absorbed by the human body. The closer the distance of human body to the BTS, the higher the rate of radiation absorbed by the body and the higher the possibility of occurrence of illness.

Majority of the selected BTS were located very close to residential or official buildings. Some were within 3.5 m radius from the foot of the antenna to residential buildings which fail to comply with the safety limits of 4.35m as suggested by the Institute of Electrical Electronics Engineers (IEEE, 1999).

5.2 Summary

The radiofrequency radiation exposure from the selected mobile base stations around Sabon gari, Giwa and Zaria Local Government Areas of Kaduna state pose no health risk to people living close to the telecommunication masts.

However, long term exposure to these mobile base stations may become harmful as most of the base stations within the study area fail to comply with distance safety limits of proximity to living areas

5.3 Recommendations:

- The ICNIRP set maximum limits for RF exposure, but it does not take into consideration long term effects of RF exposure and non thermal effects of RF exposure**.** A research into the long term effects and non thermal effects of radiofrequency radiation should be carried out.
- For those network providers that need to install their base stations close to residential areas, electromagnetic shields should be used to cover the residences to protect lives against radiofrequency radiation exposure hazard.
- Buildings located close to the BTS should use reflective window mirrors as shields against the radio frequency radiation emitted from the antennas.

REFERENCES

Achudume, A., Onibere, B., Aina, F. and Tchokossa, P. (2010). Induction of Oxidative Stress in Male Rats Subchronically Exposed to Electromagnetic Fields at Non-thermal Intensities. Electromagnetic Analysis & Application. 2: 507-512.

Agarwal A., Deepinder F., Rakesh K., Sharma R.K., Ranga G., and Li J. (2007). Effect of cell phone usage on semen analysis in men attending infertility clinic: an observational study'. Fertility and Sterility. InPress (available on line - doi:10.1016/j.fertnstert.2007.01.166).

Agarwal A., Prabakaran S.A., Ranga G., Sundaram A.T., Shama R.K., and Sikka S.C.(2006). Relationship between cell phone use and human fertility: an observational study. Fertility and Sterility 86 (3) Supplement1 S283. Retrieved June 20, 2016 from http://tinyurl.com/28rm6n.

Al-Awadi,M.Y.,Hala,A.,Mohamed,T.H.,Naima,N.,AndMohamed,A. (2013). Probable effects of exposure to EM waves from video display terminals on some visual functions. *Scholarly journal of medicine.* 3:43-47.

Andrea Carolina Lopez (2007). Human Health/Environmental Health and Science and Technology. Petition: No. 208.

Andrew, G. (2008). The Cell Phone and The Cell. The Effects of Electromagnetic Radiation. 1st Helenic Congress. Thessalonica.

Anonymous (2016). How to Shield Your House from Electromagnetic Radiation. Retrieved September 19, 2016. From www.home-biology.com/eclectromagnetic-shielding-guide/how-to-shield-your-house-from-electromagnetic-fields.

Baltrenas Pranas and Buckus Raimandas (2011). Indoor measurement of the power density close to mobile station antenna. The 8th International Conference of Environmental Engineering, Vilnius Lithuania.

Belyaev I (2005). Non-thermal biological effects of microwaves, microw. Rev. 11:13-29

Bevelaqua and Peter J. (2015). Types Of Antennas" (http://www.antenna-theory.com/antennas/main.php). Antenna Theory. Antenna-Theory.Com. Retrieved August 8, 2015.

Bhat, M.A. (2013). "Effects of Electromagnetic Waves Emitted by Mobile Phones On Male Fertility*," Computer Engineering and Intelligent Systems*, 4(3).

Blackman C.F, Wilson B.W., Stevens R.G., Anderson L.E. (2008). ELF effects on calcium homeostasis. Extremely Low Frequency Electromagnetic Fields: the Question of Cancer. Battelle Press, Columbus, Ohio.PP 189-208.

Blackman C.F., Benane S.G., Kinney L.S., House D.E., and Joines W.T.(2009). Effects of ELF fields on calcium-ion efflux from brain tissue in vitro'. Radiation Research 92: 510-520.

Blank M. and Goodman R.(2010).Stimulation of stress response by low frequency electromagnetic fields possibility of direct interaction with DNA 2010. IEEE Trans Plasma Sci 28 168-172.

Blettner M., Schlehofer B., J Breckenkamp, Kowall B., Schmiedel S., Rels U., Potthoff P., Schuz J., and Berg G Beckhoff (2008). Mobile phone base station and adverse health effects: phase 1 of a population-based cross-sectional study in Germany. *Occupational Environmental Medicine*. 66(2):118-23.doi:10.1136/oem.2007.037721. Epub.Nov 18.

Bolaji, O.A., and Idowu, P.F.(2012). Risk Associated with Low Level RF exposure at close proximities to mobile phone base stations. *The Pacific Journal Of Science* 13(2), 331-335.

Carl Smith (1969). Standard Broadcast Antenna Systems. 2-1212. Cleveland, Ohio; Smith Electronics, Inc.

Carolyn, N.K, (2007). The Physics of cell phones, Yale New Haven Teachers Institute

Chu Q., George S.T., Lukason M., Cheng S.H., Schedule R.K. and Eastman S.J. (2001) EGTA enhancement of adenovirus-mediated gene transfer to mouse tracheal epithelium in vivo. Human Gene Therapy 12: 455-467.

Climate Science Investigation (2013). Electromagnetic Radiation. Radiation from the sun. Retrieved 23 June, 2016 from www.ces.fau.edu/ces/nasa/images/energy/radiation intensityvswavelength.jpg

Diem E., Schwarz C., Adlkofer F., Jahn O. and Rudiger H. (2005). Non-thermal DNA breakage by mobile phone radiation (1800 MHz) in human fibroblasts and in transformed GFSH-R17 rat granulosa cells in vitro'. Mutation Research / Genetic Toxicology and Environmental Mutagenesis 583: 178-183.

Dina Simunic (2000), "Measurement and exposure assessment for standard compliance". University of Zagreb, Faculty of Electrical Engineering and Computing 10000 Zagreb, Croatia. PP 1 – 11.

Dina Simunic (2014), Radiofrequency Power Density Measurements of Telecommunication Masts around Some Selected Areas in Delta State. *Journal of Natural Sciences*.4 (15):2224-3186.

Dreamstime (2016). Telecommunication mast image. Retrieved June 23, 2016, from www.dreamstime.com/royalty-free-stock-photo-telecommunication-mast-mage16285275.

Ekata E. Godfrey (2015**).** A Model for Assessing base Stations for Compliance with Safety Limits for Human Exposure to Electromagnetic Fields (EMFs) in Nigeria. *International Journal of Engineering Research &Technology*. 4 (6):791-798.

Elliot P., Mireille B. Toledona, Bennett J., Beale L., de Hoogh K., Best N. and D. J. Briggs (2010). Case Control Study of Cancer Incidence of Early Childhood and Proximity to Mobile Base Stations. Mobile Telecommunications and Health Research Programme. PP 1-5.

Eltiti S., Wallace D., Ri dgewell A, Zougkou K., Russo R., Sepulveda F., Mirshekar-Syahkal D., Rasor P., Deeble R., and Fox E. (2007). Does short-term exposure to mobile phone base station signals increase symptoms in individuals who report sensitivity to electromagnetic fields?.A double blind provocation study. Retrievd July 13, 2016 from http://tinyurl.com/39ddyv.

Fejes I., Zavaczki Z., Szollosi J., Koloszar S., Daru J., Kovaks L., and Pal A.(2006). 'Is there a relationship between cell phone use and semen quality?*'Arch Androlog y* 51: 385-393.

Firstenberg A (1997). Microwaving our planet: the Environmental impact of the wireless revolution, cellular phone taskforce Brooklyn, NY 11210.

Girish Kumar (2010). Advantages and Disadvantages of Cell Phone Technology. Report on Cell Tower Radiation. Report sent to Departmant of Telecommunications, Delhi, India.

.

Godfrey E. Ekata (2015). A Model for Assessing base Stations for Compliance with Safety Limits for Human Exposure to Electromagnetic Fields (EMFs) in Nigeria. *International Journal of Engineering Research & Technology*.4(6): 791-798.

Ha B-Y. (2005). Stabilization and destabilization of cell membranes by multivalent ions. Phys Rev E 64: 051902. Retrieved June 02, 2016 from http://www.healthleadsuk.com/e/mechanism-to-explain-the-damage-

Hawley T, and Gunner M (2009). How early experiences affect brain development. Retrieved July 17, 2016 from http://tinyurl.com/5u23ae

Hill E.L and Frith U. (2006). Understanding autism: insights from mind and brain. Phil Trans R SocLond B 358**:** 281-289.

Huttenlocher P.R. and Dabholkar A.S.(2007). Regional differences in synaptogenesis in human cerebral cortex. *Journal of Comparative Neurology* 387**:** 167-178.

Ian Poole (2016). Spectrum Analyzer Basics Tutorial. Retrieved July 27, 2016 from www.radio-electronics.com/info/t_and_m/spectrum_analyzer/rf-analyzer-basic-tutorial-php

Ibitoye A.Z and Aweda A.M (2011). Assessment of Radiofrequency power density distribution around GSM and broadcast antenna mast in Lagos city, Nigeria. *Nigeria Quarterly Journal Of Hospital Medicine*, 21(1):35-40.

ICNIRP. (2010). Guidelines for Limiting Exposure to Time-Varying Electric, Magnetic and Electromagnetic Fields (up to 300 GHz). *Health Physics*. 74(4):494-522.

IEEE. (1999). Standard for Safety Levels With Respect to Human Exposure to RF Electromagnetic Fields 3 kHz to 300 GHz. IEEE Std. C95.1-1999.

Ike, E.E. (2010). Ionizing Radiation, Man and the Environment. Unijos Inaugural Lecture Series 43:PP 13-28.

International Telecommunication Union (2009). Guidance on complying with limits for human exposure to electromagnetic fields. Retrieved May 27, 2016 from http://www.itu.int/rec/TREC-K.52-200412-S !!PDF-E.pdf

Jagbir Kaur and Dhami A.K (2012), Orientation studies of a cell phone mast to assess electromagnetic radiation exposure level", *International Journal Of Environmental Sciences*. 2(3):77-79.

Jauchem J.R. (2008). Effects of low level radio frequency (3kHz to 300GHz) energy on human cardiovascular, reproductive, immune and other system: a review of recent literature. *International Journal of Hygiene and environmental health*. PP 1-29 211.

Jim Lucas (2015). What is Infrared Radiation? Live Science, Planet Earth. Retrieved 31 May 2016 from http://www.livescience.com/50260-infrared-radiation.html *Journal of Natural Science Research*.4 (15):77-79.

Karunarathna, M. A. A., and Dayawansa, I.J.(2006). Energy Absorption by the Human body from RF and Microwave Emissions in Sri Lanka, *Sri Lankan journal of Physics* 7:85-87.

Kavokin, A., Lotter, F. (2008). The Puzzle of Magnetic Resonance Effect on the Magnetic Compass of Migratory Birds. Physico-Technical Institute Polytechnicheskaya 26, St-Petersburg 194021, Russia.

Kwan – Hoong Ng (2004). Radiation, Mobile Phones, Base stations and your Health, Malaysian Communications and Multimedia Commission.PP.1-21.

Kyle Isreals (2004). An Introduction to Communication Antennas. *Proceedings Paper for Engineering 302 Spring 2004*. PP 1-9.

Lai H. and Singh N.P., (1996). Single and Double Strand DNA breaks in rat brain cells after acute exposure to radiofrequency electromagnetic radiation. *International Journal of Radiation Biology.* 69(4): 513-21.

Lebanese Atomic Energy Commission (LAEC) (2010). Scientific Review on Non-Ionizing Electromagnetic Radiation in the Radiofrequency Spectrum and its Effects on Human Health. Retrieved from http://www.wirelesshealth.org.br/downloads/LASR2010-ProtectionStandards-Policies.pdf

Mahram, M. and Gazavi, M.(2013) "The effect of extremely low frequency electromagnetic fields on pregnancy and fetal growth and development", *Arch Iranian Med*.16:221-224.

Manivannan A., (2013). Non Ionising EM Radiation: Sources, Applications and Protection. Radiation Protection Service. NHS Grampian. PP 1-8.

Media Advisory; Apply Now to Attend The ALMA Observatory Inauguration"(http://www.eso.org/public/announcements/annl1292/). *ESO Announcement*, Retrieved 4 December 2012.

Melikov K.C., Frolov V.A., Shcherbakov A., Samsonov A.V., Chizmadzhev Y.A.,Chernomordik L.V., (2001). Voltage induced nonconductive prepores and metastable single pores in unmodified planar lipid bilayer. *Biophys Journal* 80: 1829-1836

Mosteller R. D.,(1987). Calculation of Body Surface Area. New England Journal of Medicine. 317:1098.

Parker, S.P., (1989). Dictionary of Scientific and technical Terms. 4th Ed. McGraw Hill Co. NY.

Persson B.R., Salford L.G and Brun A. (1997). Blood-brain barrier permeability in rats exposed to electromagnetic fields used in wireless communication. Wireless Networks 3 PP 455-461.

Ronni Wolf MD and Danny Wolf (2004).Increased incidence of cancer near a cell phone transmitter station. *International Journal of Cancer Prevention*. 1(2):1-19.

Santini R,, Santini P.,Danze J.M.,LeruzP.,And Siege, M, (2002). Symptoms experienced by people living in vicinity of cell phone base station. *PatholBiol* . 50: 1-7.

Schantz, Hans Gregory (2003). "Introduction to ultra-wideband antennas" (http://wwwresearchgate.net/profile/Hans_Schantz/publication/4056610_Introduction_to_ultra-wideband_antennas/links/00b7d52a8a5d128046000000.pdf) (PDF), Proceedings of the 2003 IEEE UWBST Conference

Stam R. (2011). Comparison of international policies on electromagnetic fields (power frequency and radiofrequency fields).Assessment of electromagnetic radiation from base station antennas *India Journal of Radio & Space Physics, 41*: 557-565 Retrieved June 04, 2016 from http://ec.europa.eu/health/electromagnetic_fields/docs

Steve Gamble (2016). The Dangers of EMF radiation, protection and advice against microwave, electrical and electromagnetic radiation. *Equiliara*. Retrieved March 06, 2016 from http://www.equilibrauk.com/emfsbio.shtml

Thomas Haumann, UweMünzenberg , Wolfgang Maes and Peter Sierckhf (2009). Radiation Levels of GSM Cellular Phone Towers In Residential Areas. Environmental Testing & Technology, Inc., 1106 Second Street, Encinitas CA 92024, USA. PP 1-7.

Umar S. (2016). Assessment of Radiofrequency Radiation Exposure from Selected Mobile Base Stations in Zaria and Environs Nigeria. Unpublished MS.c Thesis. Ahmadu Bello University, Zaria.

Ushie P.O, Victor U.J.Nwankwo, Ayinmode Bolaji and Osahun.O.D.(2013). Measurement and Analysis of Radiofrequency Radiation Exposure Level From Different Mobile Phone Transceiver Stations in Ajaokuta and Environs. Nigeria. *Journal of Applied Physics* 3.(6): 17-21.

Victor U.J., Nwankwo, Norbert N. Jibiri, Silas S. Dada, Abraham A. Onugba1 and Patrick Ushie (2010). Assessment of Radio-Frequency Radiation Exposure Level from Selected Mobile Base Stations (MBS) in Lokoja, Kogi State, Nigeria. S. N. Bose National Centre for Basic Sciences, Kolkata 700098, India. Pp 1-12.

Viktor Schauberger (2007). Coats and Callum, the Water Wizard. Retrieved 02 June, 2016 from merlib.org/node/4662.

Wojcik, D., Topa, T. and Szczepanski K. (2005). Absorption of EM energy by human body in the vicinity of GSM base station antenna. *Journal of telecommunications and information technology*, 32(4): 34–38.

World Health Organization (2006) Electromagnetic Fields and Public Health. Media Centre fact sheet 304. Retrieved 31 May, 2016 from www.who.int/mediacentre/factsheets/fs304/en.

APPENDIX A
MEASURED RADIATED POWER TABLE (dBm)

Radiated power (dBm) at different distance					
	20	**40**	**60**	**80**	**100**
NETWORK STATIONS					
MTN	-65.43	-65.55	-65.45	-65.68	-65.40
AIRTEL	-65.12	-65.32	-65.32	-64.95	-65.69
GLO	-65.33	-65.16	-65.24	-65.30	-65.21
MTN	-61.93	-61.8	-61.88	-67.48	-67.75
MTN	-66.44	-68.66	-67.41	-66.93	-67.58
ETISALAT	-67.67	-68.11	-67.55	-67.91	-68.19
AIRTEL	-67.70	-68.21	-68.23	-67.90	-68.71
ETISALAT	-67.87	-68.12	-68.30	-68.41	-68.45
ETISALAT	-67.99	-61.23	-61.28	-60.75	-61.59
AIRTEL	-64.23	-65.32	-65.10	-65.31	-64.62
MTN	-63.11	-63.14	-63.14	-63.12	-63.13
AIRTEL	-62.99	-63.01	-63.03	-63.05	-63.07
GLO	-63.00	-63.02	-63.03	-63.05	-63.15

APPENDIX B
CONVERSION TABLES

Conversion table from measured received power (dBm) to power in Watts

Radiated power in nano Watt (nW) at different distances					
	20	**40**	**60**	**80**	**100**
NETWORK STATIONS					
MTN	0.29	0.28	0.29	0.27	0.29
AIRTEL	0.31	0.29	0.29	0.32	0.27
GLO	0.29	0.31	0.30	0.30	0.30
MTN	0.64	0.66	0.65	0.18	0.17
MTN	0.23	0.14	0.18	0.20	0.16
ETISALAT	0.17	0.16	0.18	0.16	0.15
AIRTEL	0.17	0.15	0.15	0.16	0.14
ETISALAT	0.16	0.15	0.15	0.14	0.14
ETISALAT	0.16	0.75	0.75	0.84	0.69
AIRTEL	0.38	0.29	0.30	0.29	0.35
MTN	0.49	0.49	0.49	0.49	0.49
AIRTEL	0.50	0.50	0.50	0.50	0.49
GLO	0.50	0.50	0.50	0.50	0.48

Following table gives conversion values of power density for an antenna gain Gi = 2 for different values of power received **(**Girish, 2010**).**

Table : Conversion table from measured power in dBm to Power density in Wm^{-2}

BTS	**Measured power in dBm**	**Power density in Wm^{-2}**
1	0	70.686
2	-4	28.274
3	-6	17,756
4	-10	7,069
5	-12	4,460
6	-14	2,814
7	-16	0.001776
8	-18	0.00112
9	-20	0.00707
10	-22	0.000446
11	-24	0.0002814
12	-26	0.000177
13	-28	0.000112
14	-34	0.000028
15	-36	0.0000178
16	-46	0.00000178
17	-56	0.000000178

Following table gives values of electric field and power density for an isotropic antenna Gi = 1for different values of power received **(**Girish, 2010**)**.

Table **:** Conversion from power in dBm to Power density in Wm^{-2}

BTS	**Measured power in dBm**	**Power Density in Wm^{-2}**
1	0	0.12
2	-5	0.038
3	-10	0.012
4	-15	0.0038
5	-20	0.0012
6	-25	0.00038
7	-30	0.00012
8	-35	0.000038
9	-40	0.000012
10	-45	0.0000038
11	-50	0.0000012
12	-55	0.00000038
13	-60	0.00000012
14	-65	0.000000038
15	-70	0.000000012