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EXPOSURE OF THE PUBLIC TO RF FIELDS IN MULTI-TRANSMITTER ENVIRONMENTS

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BY

COLLINS KAFUI AZAH

Thesis submitted to the Department of Physics of the School of Physical Sciences, College of Agriculture and Natural Sciences, University of Cape Coast, in partial fulfilment of the requirements for the award of Doctor of Philosophy degree in Physics

JULY 2018

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DECLARATION

Candidate's Declaration

I hereby declare that this thesis is the result of my own original research and that no part of it has been presented for another degree in this university or elsewhere.

.... Date 30-4-2020

Collins Kafui Azah

(Candidate)

Supervisors' Declaration

We hereby declare that the preparation and presentation of the thesis were supervised in accordance with the guidelines on supervision of thesis laid down by the University of Cape Coast.

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.... Date 30/04/2020

Dr. Frederick Sam

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ABSTRACT

A contributory reason for the general heightened sense of concern about RF radiations may be the announcement by the International Agency for Research on Cancer (IARC) in 2011 that mobile phone radiations are possibly carcinogenic. It may also be due to lack of reliable and accessible information and the misunderstanding that arises thereof. This research attempted to address this problem by making detailed examination of the nature and level of the RF fields in multi-transmitter environments using a log periodic RF antenna coupled to an Anritsu Spectrum analyser by a coaxial cable with a load impedance of 50 Ω. The spatial average plane wave electric field strength obtained ranged from 0.9 ± 0.1 mVm^{-1} to 1181.8 ± 166.6 mVm^{-1}. The maximum plane-wave electric field strength transmitted into wet skin was 0.2276 ± 0.0321 Vm^{-1}. This value was 2.28% more than the field strength transmitted into dry skin at the same frequency and location. SAR values ranged from 24.34 ± 3.43 μW/kg to 2.10E-05 ± 2.99E-06 μW/kg. The estimated worst-case scenario maximum energy associated with the transmitted electric fields was 1850.23 ± 261.13 MJ in dry skin. The highest power density determined was 3.70 ± 0.51 mW/m^2. The total exposure quotient was 0.004% of the recommended limit of unity. The levels of the electric fields in the multi-transmitter environment assessed were well within the recommended limits of ICNIRP. The SAR associated with the field strength levels transmitted into the tissues equally complied with the recommended ICNIRP limit. The results compared well with those published by Deatanyah et al. The methodology employed may be potentially applied for improved exposure assessment in multi-transmitter environments.

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KEYWORDS

Electric fields

Exposure quotient

Estimated energy

Power density

Radio frequency fields

Specific absorption rate

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DEDICATION

To my family.

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LIST OF ACRONYMS

AC	Alternating Current
A_F	Antenna Factor
AGNIR	Advisory Group on Non-Ionising Radiation
AM	Amplitude Modulation
ANSI	American National Standard Institute
ARPANSA	Australian Radiation Protection and Nuclear Safety Agency
BIPM	International Bureau of Weight and Measures
BRs	Basic restrictions
BTS	Base Transceiver Station
CF	Calibration Factor
DCS	Digital Cross-connect System
DECT	Digital Enhanced Cordless Telecommunications
RFID	Radiofrequency Identification
ECC	Electronic Communication Committee
EHF	Extremely High Frequency
EM	Electromagnetic
EME	Electromagnetic Emission
EMF	Electromagnetic fields
ETSI	European Telecommunications Standards Institute
FCC	Federal Communications Commission
FM	Frequency Modulation
GHz	Giga Hertz

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GPS	Global Positioning System
GSM	Global System for Mobile communications
IARC	International Agency for Research on Cancer
ICNIRP	International Commission on Non-Ionizing Radiation Protection
IEEE	Institute for Electrical and Electronic Engineers
IR	Infra-Red
IRPA	International Radiation Protection Association
ISP	Internet Service Provider
ITU	International Telecommunications Union
kHz	Kilo Hertz
MHz	Mega Hertz
MPE	Maximum Permissible Exposure
MRI	Magnetic Resonance Imaging
MTHR	Mobile Telecommunication and Health Research
NCA	National Communication Authority
NIEHS	National Institute of Environmental Health Sciences
NIH	National Institutes of Health
NIR	Non-Ionizing Radiations
NRC	National Research Council
PCS	Personal Computer Systems
PVC	Polyvinyl Chloride
QoS	Quality of Service
RF	Radio Frequency

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RPO	Radiation Protection Officer
SAR	Specific Absorption Rate
SHF	Super High frequency
TETRA	Terrestrial Trunked Radio
TV	Television
UMTS	Universal Mobile Telephony System
UHF	Ultra-High Frequency
UV	Ultra Violet
VDU	Video Display Units
VHF	Very High Frequency
WHO	World Health Organization

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CHAPTER ONE

INTRODUCTION

Background to the Study

Everybody is exposed to some form of radiation at different times. Some persons are not even aware of the existence of these energies in motion that they are exposed to. Several others equally are unaware of the possible effects that might arise from being exposed to radiations. Individuals who are aware of their plight might find ways and means of mitigating possible exposure effects. There is a call for documentation of evidence of the nature and levels of radiations everyday people are exposed to because of the existence of these radiations in the environment that none can avoid (WHO, 2010). This call is in the right direction, as the findings will inform regulators decisions regarding licensing and operation of sources of these radiations. With the current increase in knowledge about the application of electromagnetic spectrum, more devices are likely to be deployed in the near future. This will lead to an increase in the levels of ambient radiation levels. More Ghanaians now use mobile phones than in the past ten years. Most people have more than one handset whilst others use phones with the capability to operate two or more numbers on either the same network or on different networks.

Within the last decade, the telecommunication industry in Ghana has undergone tremendous growth. Technology has also taken deep roots in the daily livelihood of the citizenry, especially the urban folks. The National Communications Authority (NCA) as at the fourth quarter of 2014 has licensed 376 FM radio stations in Ghana out of which 293 are operational. The

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FM stations are made up of 36 Public radio stations, 63 Community radio stations, 16 Campus radio stations and 261 Commercial radio stations (National Communication Authority [NCA], 2014a). In all, 29 TV operators were licensed by the NCA in Ghana. Out of the 29 TV stations, 21 stations are Free-on-air, seven are Pay-Per-View and one is for research purposes (NCA, 2014b).

Currently, there are six major operators in the telecommunication industry in Ghana, operating some 6000 cell sites with about 30 million subscribers. These companies are Xpresso, Millicom (Tigo), Scancom (MTN), Vodafone, Airtel and Globacom. Amoako (2009) pointed out that 3091 cell sites were operational across the country as at 2009, servicing about 12.3 million mobile phone users. That figure shot up to 30 million users in December 2014 (NCA, 2014). Mobile Voice subscriber base in Ghana grew from 29,990,581 in October 2014 to 30,360,771 as at the end of December 2014 (Table 1) whilst Mobile Data figures in Ghana rose from 15,710,652 subscribers in November 2014 to peak at 15,805,925 at the end of December, 2014 (NCA, 2014).

Some 124 Internet Service providers (ISPs) are operational in Ghana as well. An increased subscriber base will call for more base stations to be deployed to maintain or increase the Quality of Service (QoS). The radio spectrum is a scarce natural resource which has to be managed efficiently in order to allow all eligible users the opportunity to provide communications in Ghana.

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Worldwide, efforts are devoted to research aimed at the viability of the application of frequencies as low as 400 kHz through to microwave frequencies as high as 10 GHz in therapeutic applications.

Table 1- Telecom Voice Subscription Trends in 2014

Mobile Operators	September	October	November	December
Xpresso	120,108	118,171	120,667	119,059
Millicom (Tigo)	4,012,580	4,056,322	4,100,172	4,133,760
Scancom (MTN)	13,546,678	13,478,525	13,666,766	13,852,398
Vodafone Mobile	6,870,223	7,128,764	7,137,501	7,069,516
Airtel	3,790,636	3,742,970	3,756,656	3,735,656
Glo Mobile	1,474,988	1,465,829	1,437,400	1,450,382
TOTAL MOBILE	29,815,213	29,990,581	30,219,162	30,360,771

Source: NCA (2014)

The areas of such determined efforts include cancer therapy and detection, ophthalmology, urology, cardiology, surgery and more. However, safety issues concerning the possible biological effects of electromagnetic (EM) radiations have been a matter of concern (Vorst, Rosen & Kotsuka, 2006). There have been several studies aimed at the potential adverse human health and biological effects from the application of electromagnetic fields over the years.

Characterisation of Electromagnetic Fields

Radiation is a means of propagation of energy in the form of waves or particles through space or some other medium. Electromagnetic radiation, precisely, refers to the wave-like mode of transmission in which energy is carried by electric (E) and magnetic (H) fields. These fields change in planes

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perpendicular to each other as well as to the energy propagation direction. On Earth all forms of life has adapted to the naturally low frequency electromagnetic fields and to the Earth's static geomagnetic field as well.

A field, being the space around a body radiating electromagnetic oscillations, can exert force on bodies, which lies within it. Electromagnetic field is a term used to suggest the presence of electromagnetic energy at a location of interest. Electromagnetic fields are quantified in terms of electric (E) and magnetic (H) field strengths (International Commission on Non-Ionizing Radiation Protection [ICNIRP], 2009a).

The application of electromagnetic fields (EMF) is one of the fastest growing environmental influences. It has led to anxiety and speculations about its evolving capabilities. Our environment consists of both natural and man-made electromagnetic fields. The latter is produced either intentionally (as is in the case of antennas) or as by-products of the use of electrical systems.

Naturally, electric fields are produced during thunderstorms when electric charges in the atmosphere build-up. Populations all over the world are currently expose to diverse degrees of EMF. These levels will persistently increase as technology advances. Radiofrequency (RF) energy has always been part of our environment. It is a subcategory of that section of the electromagnetic spectrum referred to as Non-Ionizing Radiations (NIR) (Figure 1). RF radiation has energy with frequency within the range of 3 KHz – 300 GHz in the electromagnetic spectrum (Cember and Johnson, 2009). Man-made electromagnetic field sources which form a major part of modern and industrialized life exist at the relatively long wavelength (low frequency) end of the electromagnetic spectrum in Figure 1.

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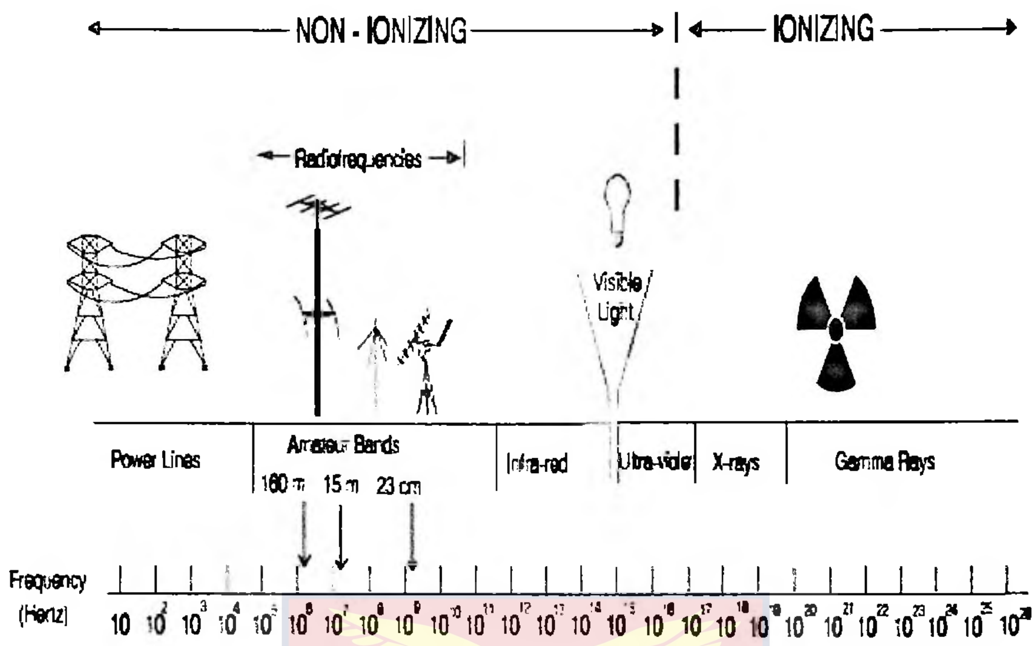

Figure 1: The Electromagnetic Spectrum (FCC, 1997).

The strongest fields which humans are exposed to, result from the intentional use of the physical properties of fields. These include, but not limited to, telecommunication devices, heating (industrial heating of materials and cooking hobs), remote detection of objects and devices (Radiofrequency Identification [RFID], radar) and diagnostics and therapeutic medical devices (magnetic resonance imaging [MRI], hyperthermia). There exist also the unintended generated fields like those associated with electronic circuits, motors and processors.

Statement of the Problem

Undoubtedly, the single most common use of RF radiation in Ghana is in communication. The most used frequency band in Ghana is between 87.50 MHz and 2.60 GHz. Services operating in this band include, but not restricted to, Frequency Modulation (FM) broadcast radio transmission, Television (TV)

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broadcast and Mobile Telecommunication. The number of TV and VHF radio broadcasting stations has increased considerably over the past twenty plus years. The need for full coverage with TV, telecommunication and VHF radio has resulted in many lower power repeater transmitters being installed to bring the services to local communities. These, coupled with other unintentional transmitters give rise to situations of simultaneous exposure of persons to RF fields of diverse frequencies from multiple transmitters. Currently, in Ghana frequencies below 9 kHz have not been allocated to any service provider. However, frequencies between 9 kHz and 2.690 GHz are allocated to services as displayed in Table 2.

Quite a number of studies have been done on the safety status of mobile cell telephone, Base Transceiver Stations (BTS), and FM radio base stations as well as ensuring that dose to the public and workers are within acceptable standards. However, there is still work to be done to comprehensively study the extent of human exposure to multiple transmitters of different frequencies transmitting at the same time. There is growing worker and public concern about the multiple towering transmitters and repeater base stations dwarfing cities and the countryside as well. A contributory reason for the general heightened sense of concern about RF radiation may be the announcement by the International Agency for Research on Cancer (IARC) that mobile phone radiations are possibly carcinogenic (IARC, 2013). It may also be due to the lack of reliable and accessible information and the misunderstanding that arises thereof (Azah, Amoako and Fletcher, 2013).

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Table 2- Frequency Allocations in Ghana

FREQUENCY BAND	GHANA'S ALLOCATION TO SERVICES
Below 9 kHz	Not allocated
9.00 – 10.05 MHz	Radionavigation Fixed Maritime Mobile Standard Frequency And Time Signal Fixed Radionavigation Broadcasting
10.05 – 108MHz	Fixed, Mobile, Broadcasting, Maritime Mobile Radionavigation, Aeronautical Mobile
108.00 – 440MHz	Aeronautical Radionavigation Broadcasting Fixed, Mobile, Amateur, Amateur-Satellite, Meteorological Aids, Space Operation Meteorological-Satellite
440.00 - 1164MHz	Fixed, Mobile, Broadcasting
1.164 - 1.700GHz	Aeronautical Radionavigation, Earth Exploration-Satellite, Radiolocation, Radionavigation-Satellite, Space Research, Broadcasting, Fixed, Mobile Except Aeronautical Mobile, Broadcasting-Satellite
1.700 – 2.010GHz	Fixed, Meteorological-Satellite (Space- To-Earth) Mobile Except Aeronautical Mobile
2.010 - 2.650GHz	Fixed, Radiolocation, Earth Exploration-Satellite, Space Operation Mobile, Amateur, Space Research Broadcasting-Satellite

Source: NCA (2014)

This research attempts to address this problem by making detailed examination of the nature and level of the RF fields in the local multi-transmitter environment and quantifying the levels in terms of electric (E) field intensities. This work as well will determine through numerical analysis, the quantity of electric field absorbed within biological tissues. The energy biological tissues extract from ambient electric field levels would be determined. The needed data stakeholders in the field of radiation protection and regulation require will also be generated by this work.

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Objectives of Research Work

The prime objective of this work is to determine whether the exposure of members of the general public living and/or operating businesses close to multiple RF transmitting antennas/sources is below the reference levels of ICNIRP for General Population/Uncontrolled exposure. This study will assess the exposure levels of members of the public to the radiations from RF antennas at public access points and as well characterise the RF environment in terms of electric field and power density. The research focuses on the following specific objectives:

- Assess the levels of electric fields strength from multiple RF transmitters at public access points.
- Determine the power density due to multiple RF transmitters of different frequencies at selected locations.
- Establish each exposure individually by assessing the extent of exposure of members of the public to RF fields from each transmitting frequency taking into consideration existing maximum permissible emission levels set by the international standard ICNIRP.
- Determine the total exposure quotient (cumulative exposure) to simultaneous RF fields of different frequencies from the multiple transmitters.
- Determine the amount of E-field absorbed within human tissue present at the locations of measurement and use it to determine the energy imparted to the tissues.
- Calculate the Specific Absorption Rate (SAR) values due to the absorbed E-fields at various frequencies bands.

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- Make some recommendations to relevant organisations and for further studies based on the results obtained.

Significance of the study

This work will provide baseline data for the assessment of simultaneous exposure of the Ghanaian populace to varying RF fields from multiple RF sources. The results obtained will supply the relevant scientific data that will add to existing data to aid in developing regulatory guideline for the control of non-ionising radiation from RF sources in Ghana. The conclusions from the study will be disseminated to the public in order to address some of the concerns about the presence of intentional RF generators in their neighbourhood. The results from this work will enrich existing scientific knowledge in this area of study. The work is also a response to WHO research agenda for RF in 2010 (WHO, 2010) which urged scientists to quantify personal exposures in multi transmitter environments and identify the main sources of potential exposure in these environments.

Delimitations

The work will cover all detectable RF radiating sources between 87.5 MHz and 2.6 GHz only due to the unavailability of equipment and accessories to cover higher and lower frequencies than stated. Measurements are limited to 10 locations each within Accra, Kumasi and Takoradi for lack of adequate funding and logistics to expand the work to cover the entire country. Each of the locations will have within 500 m to 1 km radius about it, at least two telecommunication base stations. In all cases, the assessment of the induced

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field is limited to macro level, i.e., the averaged induced field across cells. The dispersal of induced RF fields is a function of frequency, incident field strength, incident field angle, field impedance, incident field distribution, polarization, size and shape (posture) of the biological body, tissue distribution, and dielectric characteristics of the tissues, among many others. This work assumes normal incident field angle and an upright body posture. Analysis of transmission of electric field into tissues at Air-tissue interface was limited to the eye and the skin because these are the two main organs that have air-tissue interface.

Limitations

The length of the coaxial cable connecting the antenna to the spectrum analyser is 1 m. The antenna needs to be rotated during the logging of data. The closeness of the antenna to the body of the researcher will cause some perturbation of the fields.

Arrangement of Thesis

The research work has been arranged in this volume as follows; in chapter one, there are introductory notes on electromagnetic waves and radiofrequency fields with emphasis on their applications in communication and in industry. The purpose of the work and the arrangement of the thesis are also included in this chapter. Chapter two reviewed the state of scholarly work in the thesis area and theories guiding the thesis. Chapter three elaborates on the procedures and equipment used in data collection. In chapter four, data obtained from the study was analysed and presented either in tables or in

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figures. The significance of the results obtained was discussed along with their implications in relation to other relevant published works. Chapter five draws conclusions regarding the significance of the study and made recommendations to individuals, organizations and for further study based on the results of this study.

Chapter Summary

This Chapter introduced the reader to how the demand for modern electronic communication has necessitated the increasing release and licensing of more electromagnetic spectrum for electronic communication purposes. The research problem underlying this study had been explained. The objectives this study aims to achieve were clearly stated. The significance of the study are enumerated. Limitations imposed on the study were discussed. Finally, the chapter provided an account of how the study has been arranged.

Everyone is exposed to some form of radiation at different times. The nature and levels of radiations everyday people are exposed to needs to be documented to inform the general public about their exposure. Ghana has 293 operational FM stations, 29 operational TV stations and six operators in telecommunication as at the last quarter of 2014. All these services emit significant amount of electric fields. The work is a response to WHO research agenda for RF in 2010 with the main objective of determining whether the exposure of members of the general public living and/or operating businesses close to multiple RF transmitting antennas/sources is below the reference levels of ICNIRP for General Population/Uncontrolled exposure. The results from this work will enrich existing scientific knowledge in this area of study.

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The work is limited to all detectable RF radiating sources between 87.5 MHz and 2.6 GHz only due to the unavailability of equipment and accessories to cover higher and lower frequencies.

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CHAPTER TWO

LITERATURE REVIEW

Introduction

This section reviews literature related to human exposure to RF (non-ionising) radiations. The review covers areas such as the electromagnetic spectrum, classification and pathways of radiofrequency radiation sources. The interaction mechanisms between RF fields and biological tissues are reviewed. A short historical account of the current exposure guidelines is given. Some research reports by recognised bodies are also reviewed.

Concept of Radiation

Radiation is the means by which energy travels (propagates) either as waves or particles within a media. Electromagnetic radiation is a term that describes the wave-like nature of the propagation in which energy is transported by both electric (E) and magnetic (H) fields. The variations in electric and magnetic field strength with time is dependent on the source of the waves alone. Many man-made electromagnetic radiation sources produce waves with their electric field strengths varying sinusoidally with time (Figure 2). The number of complete cycles in a second is the waves's frequency (f). Whiles EM waves travel at the speed of light (c) in free-space and in air, they do so more slowly in dielectric media; body tissues inclusive. The wavelength (λ) is the distance between successive peaks in a wave (Figure 2) (ICNIRP, 2009a).

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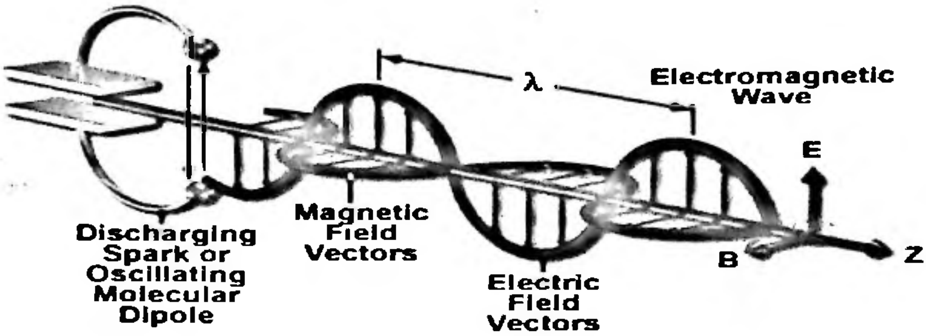

Source: ***micro.magnet.fsu.edu*** (retrieved on 16/04/2016)

Figure 2: Propagation of Electromagnetic Waves

The implications from Maxwell's equations (the basic equations of electromagnetism) are that time-varying electric fields results in time-varying magnetic fields and vice versa. Described as "interdependent", these time varying fields together form a propagating electromagnetic wave. The ratio of the electric-field strength component to that of the magnetic-field component is called the intrinsic impedance. It has different values for various media. For free-space it has a constant value of 377ohms (ICNIRP, 2009a). The quantities and units used for electromagnetic exposure assessment are summarized in Table A1 (in appendix A).

Non-Ionising Radiation

All emissions from the electromagnetic spectrum lacking a sufficiently high energy to cause ionization in matter are referred as non-ionising radiations. They have energy per photon less than about 12 electron volts (eV). Ultra violet (UV), visible light and radio waves are some examples of non-ionizing EM radiations. These forms of EM fields are largely not dangerous. Exceptions however include; IR and high-energy radio

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microwaves. These can destructively heat biological tissues. However, visible light that is intense can result in blindness. High intensity of UV can also result in blindness and surface burns of the skin in acute doses. Prolong expose to lower doses can result in skin cancer and cataracts. Non-ionising radiations are either man-made or of natural origin.

Radiofrequency Electromagnetic Radiations

Radio frequency (RF) is a name given to alternating current (AC) having the unique characteristic such that, when used as an input current to an antenna results in the generation of emissions called electromagnetic (EM) field which is suitable for either communications or wireless broadcasting or both. It extends from nine kilohertz (9 kHz) i.e. the lowest allocated wireless communications frequency, to thousands of gigahertz (GHz) of the electromagnetic spectrum.

An RF signal's frequency is known to be inversely proportional to the wavelength of its corresponding EM field. Hence at 9 kHz, the free-space wavelength is approximately 33 kilometers (km). The wavelengths are approximately one millimeter (1 mm) at the highest radio frequencies. Increasing frequency beyond the range of the RF spectrum, EM energy assumes the form of IR, visible light, UV, X-rays, and gamma rays. Countless wireless devices operate using RF radiations. Cellular and Cordless telephone, radio and TV broadcast stations and communications systems (satellite) are operated within the RF spectrum. A number of wireless devices operate at IR or visible-light frequencies (shorter wavelengths than those of RF fields). Most TV set remote-control boxes, certain types of cordless

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computer keyboards and mice, and a few wireless hi-fi stereo headsets fall within this category. The RF sub-spectrum of the EM spectrum is further divided into several ranges, or bands. Aside the lowest-frequency segment, each other segment represents an increase of frequency corresponding to an order of magnitude (power of 10). The categorisation of radio waves is shown in Table A2 (in appendix A). The Super High frequency (SHF) and Extremely High Frequency (EHF) bands form the microwave spectrum.

Sources of Radiofrequency Exposure

The RF fields originate from a different of sources; natural and man-made. The natural ambient electromagnetic fields emanates from space (extra-terrestrial sources) and from the Earth (terrestrial sources) while the man-made sources are either intentional or unintentional generators of RF fields. Relatively, natural fields are extremely small at RFs compared with man-made fields, (ICNIRP, 2009a).

Extra-terrestrial Natural Sources

The major source of extra-terrestrial electromagnetic environment is the sun. The sun produces emissions across most of the electromagnetic spectrum, i.e. visible light, ultraviolet radiation, infrared radiation, and radio waves. The radiation spectrum from the sun is, in many regards, similar to a black body with a temperature of about 5800° K. The earth receives a total energy of approximately 1000 W/m^2 from the sun at ground level. This energy is approximately 53% infrared, 44% visible light, 3% ultraviolet, and a small portion of radio waves of about 3 $\mu W/m^2$ (ICNIRP, 2009a).

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Most natural sources produce RF and optical radiations in accordance with Planck's law of black-body radiation like the sun does. The natural fields energies are likely to spread over a broad range of frequencies (Beiser, 1995). Electrical emissions in the Earth's atmosphere and cosmic radiation are other examples of Extra-terrestrial sources. According to Fixsen (2009) the remnant of heat produced during the "big bang" when the universe was formed presents itself as cosmic microwave background (CMB) radiation. This converges on Earth as black-body radiation. The frequency observed for the CMB spectrum is about 160.2 GHz. This frequency implies a temperature of 2.725 K according to Planck's law. Unlike CMB, which contributes power from all directions, RF power produced by the sun is principally incident from the direction of the sun.It is therefore reduced drastically at night (ICNIRP, 2009a).

Terrestrial Natural Sources

Majority of the radiations emitted from the Earth (terrestrial) belongs to the infrared segment of the EM spectrum. Only a very tiny fraction of about 0.0006% of the terrestrial emitted power falls within the RF region. This power density is about a thousand times larger than the RF power density emanating from the sky and the sun (ICNIRP, 2009a). Lightning is considered a terrestrial source of RF fields and has its frequency below 30 MHz. The EMFs from lightning are impulsive due to the time-varying currents and voltages associated with lightning. Waveguides are generated between the ionosphere and the Earth's surface to enable the generated RF fields to travel large distances around the Earth. NOAA (2011) pitched the average lightning

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strike on Earth at 40 times per second, or 10 times per square kilometre per year.

There exists a variety of models for determining return strokes. Return Strokes are the strongest sources of RF-EMF that is associated with lightning. (Cooray, 2003). Willett, Bailey, Leteinturier, and Krider (1990) investigated and measured the E-field strength of return strokes as a function of time. A Fourier analysis was conducted to evaluate the average spectrum between the frequency band 200 kHz to 30 MHz. It was noticed that the energy spectral density was inversely proportional to $1/f^2$ where f is the frequency. This was at frequencies below 10 MHz. The reduction beccame rapidly beyond 10 MHz.

Intentional Man-made Sources

Many intentional man-made RF fields sources exist. Radar (applied in flight control, military, traffic speed, car), medical diagnostics and therapy (magnetic resonance imaging [MRI], hyperthermia), microwave oven, Bluetooth and Wi-Fi devices, cordless and mobile phones, base stations, broadband powerlines, TV, FM and AM radio broadcast are but some few. The operate within the RF range of 30 kHz to 300. In Table A3 (in appendix A), some of these frequency bands and their applications are displayed. The primary functions of these source is to produce RF fields which are purpose specific.

Unintentional Man-made Sources

Electrical ballasts applied for fluorescent lighting, motors, processors and electronic circuits all produce electric fields as a by-product. These are

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unintentionally generated fields. They are generated as the inevitable consequence of the mode of operation of systems. They can be associated with energy loses from a process (ICNIRP, 2009a).

Exposure to RF Fields

Exposure to RF fields describes the fields from a source at a location where a person is likely to be present. This description is in terms of the electric and magnetic field strengths as well as their direction. Exposure of workers and the public can occur from different sources and in a broad variety of ways. Exposure of the public to man-made RF fields of low levels is universal. The restrictions for exposure to electric and magnetic fields (frequencies up to 10 GHz) are captured in Table A4 (in appendix A). Reference levels for public exposures to same fields are shown in Table A5 (in appendix A).

The wide spectrum of applications of RF devices for public consumption has led to a general increase in the average exposure of the members of the public above natural background levels. In the assessment human exposures, recognition is given to the fact that, as EMFs radiate away from a source there is energy stored in the vicinity of the source (not propagating). The associated reactive fields of the stored energy are much stronger than the radiated fields. The reactive near-field extends to a distance of about a wavelength from the source. The wave impedance in the reactive near-field may be higher than the impedance of free-space. This happens if a source is capacitive in nature. The reverse is the case if a source is inductive in

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nature (Advisory Group on Non-Ionising Radiation [AGNIR], 2003). These exposures are either personal, occupational and environmental.

Personal Exposure Pathways

A member of the public is likely to encounter several sources of RF radiation as part of daily personal life, giving rise to personal exposures. The most likely of these sources include mobile phone use, communication technologies like Bluetooth and Wi-Fi, or household devices such as microwave ovens. Of these, the mobile phone usage gives rise to the most intense personal exposure. Over the past decade, there have been extensive changes in the make of mobile phones that has important implications for RF exposure of the user.

Earlier mobile phones were analogue. They gave rise to emitted waves of 450–900 MHz. In the mid-1990s, digital phones with RF frequency capability to 2200 MHz became operational. They almost completely replaced eradicated analogue phones by 2000. The largest growth in the past decade has been for smartphones. Smartphones allow access to a broad range of non-voice data applications like Internet, games, photographs, music and videos.

Redmayne, Inyang & Dimitriadis (2010) conducted a study in one state of Australia using a modified version of the Interphone questionnaire with 317 child-respondents in secondary school (median age, 13 years), and found that 80% used a mobile phone. Data on national use of mobile phones in 2009, collected by the Australian Bureau of Statistics (ABS), puts the percentage of Australian children that had a mobile phone at 31%, with the highest ownership being in the age group 12–14 years (76%) (ABS, 2009).

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In 2005, Mezei, Benyi and Muller, (2007) found similar rates of mobile-phone use by children in three major cities in Hungary. 76% of children in secondary school owned a mobile phone, 24% used a mobile phone daily to make calls, and an additional 33% used mobile phones to make calls multiple times per week.

Occupational Exposure Pathways

There are many occupations involving potential sources of exposure to RF radiation in the workplace. The more important of these exposures involve working with high-frequency dielectric heaters (Polyvinyl Chloride [PVC] welding machines) and induction heaters, broadcast sources, high-power pulsed radars, and medical applications including MRI and diathermy. High-frequency dielectric heaters functioning at 27 MHz have traditionally involved the highest occupational exposures to RF (Allen, 1999). For dielectric heater operators, the whole-body average SAR has been estimated to vary from 0.12 to 2 W/kg and the frequently reported effects by this group of workers is heating effects (Jokela & Puranen, 1999).

NOBIS

The swift proliferation of mobile-phone use and other communication technologies worldwide has necessitated an increase in the numbers of workers to undertake monitoring and maintenance of base stations and its related equipment. In a documented worker exposure assessment by Alanko and Hietanen, (2007) during maintenance tasks at a tower with Global System for Mobile communications (GSM) 1800 antennae, the maximum instantaneous power density measured was 2.3 W/m^2. For the tower with both GSM 900 and GSM 1800 antennae, the maximum instantaneous power

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density inside the climbing space was 0.4 W/m^2. The authors concluded that exposures will depend on the different types of antennae located on the towers and that it is usually difficult to predict occupational RF exposures. Other potential sources of radiofrequency radiation in the workplace include, but not limited to, Portable radios, short-wave and surgical diathermy. Fink, Wagner, Congleton, and Rock (1999) made 986 measurements for 54 police radar units and recorded the highest power density as 0.034 mW/cm^2

Environmental Exposure Pathways

Mobile phone base transceiver stations are the commonest sources of RF in the general environment. Allen, Blackwell and Chadwick (1994) reported that most HF transmitters have powers in the range 100–500 kW and few others with powers greater than 500 kW in the United Kingdom. In an attempt to measure typical environmental exposure of humans to RF radiation over a one-week period, Swiss volunteers were asked to wear an RF exposimeter for a week and to complete an activity diary as well (Frei, Mohler & Neubauer, 2009b). It was found out that mobile-phone base stations contributed more to exposure (32.0%), than mobile-phone handsets (29.1%) and Digital Enhanced Cordless Telecommunications (DECT) phones (22.7%).

Another study of a randomly sampled persons of 200 in France used a personal exposure meter to estimate the doses, time patterns and frequencies of RF exposures. The electric-field strength within 12 different bands was measured at regular intervals over 24 hours (Viel, Clerc & Barrera, 2009).

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This allowed differentiation of different sources of RF radiation, including mobile-phone base stations. The median of the maximum levels for all three systems (GSM, Digital Cross-connect System [DCS] and UMTS) ranged between 0.05 and 0.07 V/m.

Interaction Mechanisms between RF Fields and the Body

When a biological system (animal or human) or tissue is exposed to an RF, the RF energy is either scattered or attenuated as it tunnel through body tissues. To produce a biological response, the RF must penetrate the exposed biological system and induce internal EMFs. The RF energy absorption is principally a function of the radiation frequency and the composition of the exposed tissue. Other RF-energy absorption parameters are incident field intensity and polarization, zone of exposure (near-field or far-field), characteristics of the exposed biological system (size, geometry, dielectric permittivity and electric conductivity), and absorption or scattering effects of objects near the exposed body (Stuchly, 1979).

Values for the dielectric constant and conductivity vary substantially over the RF range (30 MHz to 300 GHz). Most tissues contain a very high proportion of water. Largely, the water content of the tissue determines the penetration of a frequency-specified electromagnetic wave due to the high dielectric constant of water. The rate of energy absorbed by or deposited per unit mass of tissue per unit time is termed specific absorption rate (SAR). This relationship between the root mean-square (rms) of the induced electrical field strength $[E]^2$, the electrical conductivity (σ) and the tissue density (ρ) is given by the expression in equation 1.

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$$SAR = [E]^2 \cdot \sigma/\rho \qquad (1)$$

The SAR values can equally be estimated from measurements of the increase in temperature produced by the absorption of RF energy in tissue using equation 2.

$$SAR = C_p \cdot \delta T/\delta t \qquad (2)$$

where C_p is the specific heat of the tissue or medium, $\delta T/\delta t$ is the initial rise in temperature over time. SAR is the most appropriate metric for determining EM effect exposure in the very near-field of a Radio Frequency (RF) source (Kiminami, Iyama, Onishi and Uebayashi, 2008; and Watanabe, Taki, Nojima, and Fujiwara, 1996). SAR estimate requires the value of the mass density ρ, for each type of tissue. The specific values for σ, ε and ρ considered in this study correspond to data in literature by Moneda, Ioannidou, and Chrissoulidis, (2003)., Morega & Machedon, (2002) and Gabriel, Gabriel & Corthout, (1996).

In the near-field region, the electric and magnetic fields are decoupled and not uniform, wave impedance varies from point to point, power is transferred back and forth between the antenna and the surrounding object, and the energy distribution is a function of both the incident angle and distance from the antenna (Lin, 2007). Because the electric and magnetic fields are decoupled in the near-field, the induced field can be obtained by combining the independent strengths of the electric and magnetic fields, i.e. the electric and the magnetically induced electric fields inside the body (Lin, 2007).

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UNEP/WHO/IRPA (1993) puts the basic coupling mechanisms through which time-varying electric and magnetic fields interact directly with living matter into three established groups

- coupling to low-frequency electric fields;
- coupling to low-frequency magnetic fields; and
- absorption of energy from electromagnetic fields.

The coupling of RF energy into biological systems may be quantified by the induced electric and magnetic fields, power deposition, energy absorption, and the distribution and penetration into biological tissues. These quantities are all subjects to the physical configuration and dimension of the biological body. The established biophysical mechanisms underlying the interaction of RF radiation with cells, tissues and entire bodies include ionization potential, induced charge and dipole relaxation, enhanced attraction between cells for pearl-chains formation and other RF-induced force effects, microwave auditory phenomenon, and thermal effects as manifested in tissue temperature elevations (ICNIRP, 2009a)

A well-known mechanism by which ELF fields interact with biological tissues is the induction of time-varying electric currents and fields. At sufficiently high levels, these can produce direct stimulation of excitable tissues such as nerve and muscle cells. At the cellular level, the interaction induces voltages across the membranes of cells sufficient to stimulate nerves to conduct or muscles to contract. This mechanism accounts for the ability of humans and animals to perceive electric currents in their bodies and to experience electric shocks

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Effects of RF Fields Interactions with Living Tissue

The earliest papers which associated health effects with exposure to radiofrequency electric fields were published in the 1960's (Safigianni, & Kostopoulou, 2007). However, the first epidemiological study suggesting a positive association between EMF exposure and human health was published in 1979 (Wertheimer & Leeper, 1979). Epidemiological studies result in statistical associations rather than direct evidence of carcinogenicity, therefore other scientific work must be conducted before scientists can confirm the results from epidemiological studies. Usually, when epidemiological studies show a consistent and strong association to a risk factor, scientists will develop an acceptable theory for how such an exposure might cause disease. Laboratory studies are then conducted to test the biological mechanism. In addition, exposure studies on animals need to be conducted under controlled conditions to determine if exposure to the agent does indeed result in disease (IARC, 2002 & ICNIRP, 1998).

Epidemiology

Epidemiology is the scientific and medical study of disease origin and spread within a population as well as the development characteristics of a specific disease. These studies investigate the occurrence and distribution of diseases, in real life situations, in human populations. According to National Institute of Environmental Health Sciences Epidemiologists - National Institutes of Health (NIEHS-NIH) epidemiologists establish statistical associations between the occurrence of disease in a population and exposure to an infectious or non-infectious agent (NIEHS-NIH, 2002). Due to the

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difficulties of epidemiological studies in detecting effects and factors, such as bias, misclassification, confounding and statistical variation that can affect the outcome of the research, scientists evaluate all relevant evidence from cellular studies, animal studies and epidemiological studies when deciding about the potential health hazard (IARC, 2002 & ICNIRP, 1998).

Conclusions from Epidemiological Studies

Epidemiological studies of RF exposures and cancer show limited evidence in humans for the carcinogenicity of radiofrequency radiation. However, positive associations have been observed between exposure to radiofrequency radiation from wireless phones and glioma, and acoustic neuroma. There is also limited evidence in experimental animals for the carcinogenicity of radiofrequency radiation. Radiofrequency fields might be carcinogenic to humans. The World Health Organization (WHO)/IARC in a press release numbered 208 and dated May 31, 2011 classified radiofrequency electromagnetic fields as possibly carcinogenic to humans (Group 2B) based on an increased risk for glioma, a malignant type of brain cancer, associated with wireless phone use (IARC, 2013).

Historical Evolution of Standards for Limiting Exposure to EM Fields

Prior to World War II, hazard assessment of NIR received little or no attention from governments and authorities charged with developing safety practices for operations involving radiations (Cember and Johnson, 2009). However, the post-war electronics and communications race among nations

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and companies drew the needed attention to the possible public health aspects of NIR.

Early exposure standards were inadequate because they failed to account for important physical aspects of electromagnetic wave interaction with the body. In addition to the magnitude of the applied fields, absorption of RF energy depends on the physical geometry of the body relative to the direction of the applied fields and upon frequency dependent electrical properties of the absorbing tissue.

According to Christie (1928) following the demonstration in 1928 that high frequency RF radiation was capable of heating internal organs of the human body, another form of diathermy which does not require direct electrical contact with the skin was birthed. Shortwave diathermy equipment for medical application was a commonplace in the 1930s for deep heat therapy.

The earliest investigations into possible adverse health effects associated with the use of radar commenced soon after the Second World War. As early as in 1950s, there was evidence sufficient enough to conclude that harmful effects were associated with exposure to levels of microwave radiation above approximately 100 mW/cm^2.

The fundamental mechanism for the researched injuries was related to excess heating resulting from the absorption of the microwave energy in various tissues within the body (Schwan & Piersol 1954). In 1953, the US Navy adopted a maximum continuous exposure limit of 10 mW/cm^2 for all RF and microwave frequencies in use. In 1966, the American National Standards Institute (ANSI) published the first edition of the C95.1 Standard specifying a

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10 mW/cm^2 human exposure limit for the frequency range from 10 MHz to 100 GHz. (Australian Radiation Protection and Nuclear Safety Agency [ARPANSA], 2002). Cember et al (2009) reported that, for the first time in 1968, the U.S. congress enacted the Radiation Control for Health and Safety Act (Public Law 90-602) to safeguard the consumer from hazards associated with electronic products. The Occupational Safety and Health Act (PL91-596) was also passed that same year to safeguard radiation workers from both ionizing and non-ionizing radiations.

More than 40 years after the first enactment, today there exists many organizations charged with formulating and recommending exposure guidelines aimed at protecting workers and the general public from the harmful effects of both ionizing and non-ionizing radiations. Notable among them are ICNIRP, International Radiation Protection Association (IRPA), World WHO, the Institute of Electrical and Electronic Engineers (IEEE), and Federal Communications Commission (FCC)

Guidelines of the International Commission for Non-Ionizing Protection

ICNIRP guidelines remain the most accepted and widely used guidelines for non-ionizing radiations. The guidelines have been adopted by many organizations and countries. Some of such renowned organisations are the International Telecommunications Union (ITU) and the WHO. An excess of 30 countries worldwide also used these guidelines. Many health administrations and environmental organizations also adopted the guidelines for protection purposes. These guidelines are based on basic restrictions and reference levels. There is also an application of a two-tier system. This system

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is include general public and occupational exposure limits (ICNIRP, 1998). Physical parameters make up the basic restrictions. These parameters are vital in assuring that there will not be any adverse effect. However they are difficult to measure in the field. As a result, the basic restrictions are, are in turn, related to the reference levels. These reference levels are easy to measure in field and can be obtained from the basic restrictions applying computational models and measurement methods. This work adopted the ICNIRP guideline as a benchmark for exposure assessment.

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

The IEEE Standard for Safety Levels with Respect to Human Exposure to Radio Frequency Electromagnetic Fields, 3 kHz to 300 GHz is targeted at ensuring protection for people (workers and the public) against known health effects in human beings related to exposure to fields within the range 3 kHz to 300 GHz. The IEEE standards are formulated in basic restrictions (BRs) and maximum permissible exposure (MPE) values. Additionally, there is a system of two tiers made up of action level and controlled-environmental exposure limits. The basic restrictions restrict exposure to electromagnetic fields based on the know health effects. The MPE values are, however, derived from BRs. MPEs are limits placed on external fields as well as on both induced and contact current.

Both the BR and the MPE values consist of safety factors. The factors take into consideration uncertainties and assure a safety margin for all. It must be noted that it possible to exceed an MPE while still complying with BRs.

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This is so because the safety factors in the MPEs are far greater than the safety factors in the BRs (IEEE, 2006).

FCC Exposure Guidelines

The FCC's guidelines for Maximum Permissible Exposure (MPE) are spelt out in electric field strength, magnetic field strength and power density. The FCC guidelines are made up of two separate tier systems. The tier systems are dependent on the situation in which the exposure occurs and/or the status of the exposed person. In deciding which tier to apply in a given situation, the definitions of controlled/occupational and uncontrolled/general population exposures are considered (FCC, 1997). In the far-field of a transmitting antenna, the electric field vector (E), the magnetic field vector (H), and the direction of propagation are all taken to be mutually orthogonal.

Mobile Telecommunication and Health Research (MTHR) Review

The Independent Expert Group on Mobile Phones (Stewart Committee) was set up to examine the possible adverse health effects from mobile phones and base stations. The programme was to investigate the health aspects of mobile phone use and related technologies. Recommendations from this group led to the establishment of MTHR programme.

Until date, MTHR has published two comprehensive reports; one in 2007 and the current one in 2012. In a cohort or prospective study, the average exposure from mobile phone usage was determined in a group of people who were then followed up to see who later develops disease and to investigate

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whether there is a relationship or association, between exposure and the disease (MTHR-PMC, 2012).

In contrast, a case control study looks back at previous exposure patterns among a sample disease and a control group of people without the disease. Even though Case-control studies are usually quicker, they are more prone to bias that can distort study findings. A dozen case-control studies have reported results on the risk of brain cancers and acoustic neuromas related to mobile phone use.

Pooled analysis from five European countries (Denmark, Finland, Norway, Sweden and the UK) found no overall excess risk of glioma according to Lahkola et al (2007). However, long-term use was associated with an increased risk. The eleven-year study programme found no evidence that exposure to generally low frequency base station (mobile network) emissions during pregnancy affects the risk of developing cancer in early childhood, and no evidence that use of mobile phones can lead to an increased risk of leukaemia. MTHR report however recommends, among others, the following;

- Studies of long-term behavioural/neurological outcomes in children and/or adolescents in relation to mobile phone usage.
- Provocation studies on children
- Provocation studies to identify neurobiological mechanisms underlying possible effects of mobile phone signals and prenatal exposure on development and behavior.

MTHR report also found that the type of modulations applied to radio transmissions and signals from the public Terrestrial Trunked Radio (TETRA)

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system were both safe or at least had no evidence to support any health fears. TETRA systems are often used by the emergency services.

National Research Council EMF Research Review

In 1996, the National Research Council (NRC) published a report based on studies which covered a wide range of subject areas. The study included cellular and molecular effects, epidemiology, and animal and tissue effects. This report concluded that the body of scientific evidence available at that time does not show that exposure to EMF presents a human health hazard. No conclusive or consistent evidence has shown that exposure to residential EMF produces cancer, neurobehavioral problems, or reproductive and development effects. The NRC review did not cover occupational exposure studies (NRC, 1996). The report presented little about geographical variation in exposures in different settings in the general community.

Dielectric Properties of Tissues

The interaction of electromagnetic radiation with biological tissues at the cellular and molecular levels result in dielectric properties of biological media (Gabriel. C, Gabriel & Corthout, 1996). The theoretical aspects and the main findings in dielectric properties of biological tissues have been widely reviewed (Schwan, 1957., Schwan and Foster, 1977., Pethig, 1984., Schwan, 1957., Pethig and Kell, 1987., Foster and Schwan, 1989 and Stuchly, M. A. and Stuchly, 1980). According to Gabriel et al (1996), the interaction of the time-harmonic EMF and human body at microwave frequencies is most often described in terms of the complex permittivity

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$$\varepsilon^* = \varepsilon' - j\varepsilon'' \quad (3)$$

or the complex conductivity

$$\sigma^* = \sigma + j\omega\varepsilon_0\varepsilon' \quad (4)$$

where

ε' = the dielectric permittivity (the real part)

ε'' = the dielectric loss or loss factor (imaginary part)

σ = the electric conductivity,

ε_0 = the permittivity of free-space and

$\omega = 2\pi f$ is the angular frequency of the EMF and f is the frequency of the EMF

The variables ε'' and σ contain contributions from both dielectric relaxation and ionic conductance processes (Campbell, 1990). Stuchly and Stuchly (1980) tabulated the dielectric properties of tissues in the frequency range 10 kHz to 10 GHz. The dielectric loss is related to the electric conductivity as $\varepsilon'' = \frac{\sigma}{\omega}$ and the relative dielectric loss is given as $\varepsilon''_r = \frac{\sigma}{\omega\varepsilon_0}$. The propagation constant of the tissues is calculated from (Gabriel et al, 1996),

$$\gamma = \alpha + j\beta \quad (5)$$

where the attenuation constant of the tissue, α, is given as

$$\alpha = \left(\frac{\omega}{c}\right)\sqrt{\frac{\mu_r\varepsilon'_r}{2}\left(\sqrt{1 + (\varepsilon''_r/\varepsilon'_r)^2 - 1}\right)} \quad (6)$$

and the phase constant, β, given by (Furse, Christensen & Durney, 2009)

$$\beta = \left(\frac{\omega}{c}\right)\sqrt{\frac{\mu_r\varepsilon'_r}{2}\left(\sqrt{1 + (\varepsilon''_r/\varepsilon'_r)^2 + 1}\right)} \quad (7)$$

which yields

$$\gamma^2 = j\omega\mu(\sigma + j\omega\varepsilon') = -\mu_r\left(\frac{\omega}{c}\right)^2(\varepsilon'_r + j\varepsilon''_r) \quad (8)$$

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The wave velocity in tissue, u, and the wavelength in tissue, λ, are related to the phase constant through the following equations (Sadiku, 1994)

$$u = \frac{\omega}{\beta}, \qquad \lambda = \frac{2\pi}{\beta} \tag{9}$$

The skin-depth is the distance a plane-wave travels within a material until it decays to 1/e of its initial amplitude, and is denoted by δ (Baker-Javis and Kim, 2012). The skin-depth is related to the attenuation coefficient by $\delta = 1/\alpha$. In order to calculate the transmission coefficient in biological tissues, use was made of the intrinsic impedance of the said tissues. Mathematically,

$$\eta = \sqrt{\frac{\mu}{\varepsilon^*}} = \eta_0 \sqrt{\frac{\mu_r}{\varepsilon'_r - j\varepsilon''_r}} \tag{10}$$

$$|\eta| = \eta_0 \sqrt{\frac{\mu_r}{\varepsilon'_r[1 + (\varepsilon''_r/\varepsilon'_r)^2]^{0.25}}} \tag{11}$$

A four-term Cole-Cole expression of the frequency dependence of tissue material is an example of dielectric relaxation model which shows the relaxation response of a dielectric medium to an external, oscillating electric field. The expression is given as

$$\varepsilon^*(\omega) = \varepsilon_\infty + \frac{(\varepsilon_s - \varepsilon_\infty)}{1 + (i\omega\tau_0)^{1-\alpha}} \tag{12}$$

where

ε^* is complex dielectric constant

ε_s is static dielectric constant

ε_∞ is infinity frequency

τ_0 is time constant

α takes values between 0 and 1(it allows to describe spectral shapes)

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Exposure Assessment

In situations of simultaneous exposure to fields of different frequencies, it is important to determine whether these exposures are additive in their effects. ICNIRP (1998) encouraged that additivity be examined separately for thermal and electrical stimulation effects. For thermal effects, relevant above 100 kHz, SAR and power density values should be added according to:

$$\sum_{i=100\text{kHz}}^{10\text{ GHz}} \frac{SAR_i}{SAR_L} + \sum_{i>10\text{ GHz}}^{300\text{ GHz}} \frac{S_i}{S_L} \leq 1 \qquad (13)$$

where SAR_i = the SAR caused by exposure at frequency *i;*

SAR_L = the SAR limit (0.08 Wkg^{-1} for whole body average, 2 Wkg^{-1} for head and trunk, and 4 Wkg^{-1} for limbs)

S_L = the power density limit given in Table A5 and

S_i = the power density at frequency *i*.

But for this work frequency below 10 GHz were investigated and so compliance shall be determined using only the first part of equation 13 as

$$\sum_{i=100\text{kHz}}^{10\text{ GHz}} \frac{SAR_i}{SAR_L} \leq 1 \qquad (14)$$

For thermal considerations, relevant above 100 kHz, the following requirement should be applied to the field levels:

$$\sum_{i-100\ kHz}^{1\ MHz} \left(\frac{E_i}{c}\right)^2 + \sum_{i>1\ MHz}^{300\ GHz} \left(\frac{E_i}{E_{L,i}}\right)^2 \leq 1 \qquad (15)$$

where E_i = the electric field strength at frequency i

$E_{L,i}$ = the electric field reference level from Tables 6 and 7 (ICNIRP, 1998)

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c = 610/f Vm^{-1} (f in MHz) for occupational exposure and $87/f^{1/2}$ Vm^{-1} for general public exposure;

Since frequencies investigated in this work are far above 1 MHz, the second part of equation 15 was applied to the fields as

$$\sum_{i>1\,MHz}^{300\,GHz} \left(\frac{E_i}{E_{L,i}}\right)^2 \leq 1 \tag{16}$$

In comparing the results with international bodies such as ICNIRP, compliance shall be evaluated as:

$$\sum_{1}^{N} \frac{S_i^{meas}}{S_i^{guid}} = \frac{S_1^{meas}}{S_1^{guid}} + \frac{S_2^{meas}}{S_2^{guid}} + \cdots \frac{S_N^{meas}}{S_N^{guid}} \leq 1 \tag{17}$$

where S^{meas} is the measured (calculated) power density and S^{guid} is the guidance or reference power density.

Calibration Requirements

Calibration Factor

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

$$CF = \frac{E_{ref}}{E_{meas}} \tag{18}$$

It is the ratio between the expected electric reference field strength (E_{ref}) and the value (E_{meas}) read on the PC or on a dedicated receiver unit. This factor is mainly a function of frequency and, in the presence of non-linearity error, of field strength. The CF is determined as a frequency function. For each frequency, the CF value shall be known with uncertainty less than 1dB. Errors due to frequency interpolation are included in the tolerable uncertainty on CF (ITU-K.61, 2008).

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Antenna Factor

The Antenna Factor (A_F) is a common parameter of antennas used in the calculation of field strength during radiated emissions measurements, and relates the value of the incident electric or electromagnetic field to the voltage at the output of the antenna. For an electric field antenna, this is expressed as:

$$A_F = \frac{E_{ref}}{V_i} \tag{19}$$

where:

A_F = Antenna Factor, m^{-1}

E = Electric field strength on the probe in Volts per meter

V_i = Voltage at the antenna terminals in Volts

It also can be shown that in a 50 ohm system:

$$A_F = \frac{9.73}{\lambda\sqrt{G_r}} \tag{20}$$

where:

G_r = the gain of the receiving antenna in dB

λ = wave length in meters

In decibels, we have

$$A_F(dB) = 20log_{10}\left(\frac{9.73}{\lambda\sqrt{G_r}}\right) \tag{21}$$

Equation 21 applies only to far-field situations and valid only for 50 Ohm systems. It is also valid when the antenna and incident field are polarisation matched and includes the effects of impedance mismatch.

Antennas used for radiated emissions testing are individually calibrated (the antenna factors can be measured directly) at all appropriate distances (Clayton, 1992). The calibrations produce values that are defined as the "equivalent free-space antenna factor." The calibration procedure corrects for

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the presence of the reflection of the antenna in the ground plane, giving the value that is measured if the antenna is in "free-space." This factor is primarily a function of frequency but, in the presence of non-linearity error, it may depend on field strength, too. The A_F is determined as a frequency function. For each frequency, the A_F value shall be known with an expanded uncertainty (i.e., 95% statistical confidence) of less than 2 dB. The maximum tolerable uncertainty includes also the error due to frequency interpolation (ITU-K.61, 2008).

RF Fields Absorption by Biological Tissues

There are four basic formulations that describe electromagnetic phenomena and are collectively referred as Maxwell's equations. Their differential forms are shown below;

Gauss's law for $\vec{E}$

$$\nabla . \vec{E} = \frac{\rho}{\varepsilon_0} \tag{22}$$

Physical interpretation: Electric flux through a closed surface is proportional to the charge enclosed

Faraday's law

$$\nabla x \vec{E} = -\frac{\partial \vec{B}}{\partial t} \tag{23}$$

Physical interpretation: Changing magnetic flux produces an electric field

Gauss's law for $\vec{B}$

$$\nabla . \vec{B} = 0 \tag{24}$$

Physical interpretation: The total magnetic flux through a closed surface is zero

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Ampere's law

$$\nabla x \vec{B} = \mu_0 \vec{J} + \mu_0 \varepsilon_0 \frac{\partial \vec{E}}{\partial t} \quad (25)$$

Physical interpretation: Electric current and changing electric flux produces a magnetic field

Maxwell's equations are consistent with the principle of conservation of charge (Nelson, 1999). The displacement and magnetic fields **D** and **B** are related to the electric and auxiliary fields **E** and **H** via the constitutive equations, whose precise form depends on the material in which the fields exist. For homogeneous, isotropic, dielectric and magnetic materials these equations read

$$D = \varepsilon E, \quad (26)$$

$$B = \mu H \quad (27)$$

where $\boldsymbol{\varepsilon}$ is the electric permittivity of the medium; a material property that indicates the ability of a material to support the formation of a magnetic field within itself and $\boldsymbol{\mu}$ is the medium's magnetic permeability; a physical quantity for the ability of a material to be polarized due to an electric field. The permittivity determines the interactions of the medium with the electric field and the dielectric constant defines the medium's ability to 'store' the field energy.

The permittivity of biological tissues is largely dependent on water and electrolyte contents. Thus, tissues with higher water content by mass such as blood, muscle, liver and kidneys, have higher dielectric constants and conductivities than low water compositions such as fat and lungs. Both the permittivity and conductivity vary with frequency and exhibit relaxation phenomena. The physical phenomenon responsible for the dispersion at low

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frequencies is counter ion polarization (Foster and Schwan, 1989). Their numerical values of permittivity and permeability in vacuum equal (WHO, 1984)

$$\varepsilon_0 = 8.854 \times 10^{-12} C^2/Nm, \qquad \mu_0 = 4\pi \times 10^{-7} N/A^2 \qquad (28)$$

The relative permittivity ε_r and relative permeability μ_r are defined as the material properties relative to vacuum, i.e.

$$\varepsilon_r = \frac{\varepsilon}{\varepsilon_0} \qquad (29)$$

$$\mu_r = \frac{\mu}{\mu_0} \qquad (30)$$

(IARC, 2002) posited that most biological tissues have a permeability equal to that of free-space (air, vacuum) (Foster et al., 1989). Many animal species, including humans, are known to have minuscule amounts of biogenic magnetite (Fe_3O_4) in their brains and other tissues (with permeability $\mu_r \geq 1$) (Kirschvink, Kobayashi-Kirschvink and Woodford, 1992). From the above two quantities **ε** and **μ** two other physical constants; the speed of light, **c** and the characteristic impedance, **η**, can be defined (Janssen and Warmoeskerken, 2006)

$$c_0 = \frac{1}{\sqrt{\mu_0 \varepsilon_0}} \qquad (31)$$

$$\eta_0 = \sqrt{\frac{\mu_0}{\varepsilon_0}} \qquad (32)$$

In vacuum, the speed of light and the characteristic impedance assume the following values;

$$C_0 = 2.998 \; X \; 10^8 \; m/s \;, \qquad \eta_0 = 376.73 \; \Omega \qquad (33)$$

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Matters Arising from Review of Related Literature

The ICNIRP, IEEE standard and FCC guidelines all recommend limits with respect to both occupational and general population exposures. These limits are based on field strength, power density and specific absorption rate (SAR). None of the standards considered the total amount of energy the human body extracts from the ambient field. This energy could be significant and could influence the body's thermoregulatory processes. According to FCC (1997) the compliance requirements for controlled/occupational and uncontrolled/general population exposures depend on a person's awareness and the ability to exercise control over his/her exposure. This is unattainable if there are no comprehensive data on the nature of the ambient electric field distribution due to installed presence of multiple transmitters giving rise to simultaneous exposures. Available scientific literature dealt predominantly with exposure of persons to individual RF sources. There are however limited reports to quantify the cumulative exposure due to these individual RF sources. In the WHO research agenda for RF in 2010, the need to quantify personal exposures in multi transmitter environments was emphasised. The WHO research agenda equally urged scientists to identify the principal sources of potential exposure of the public to RF radiations (WHO, 2010). This research work seeks to identify the main sources of potential exposure of humans to RF in multi transmitter environments and quantify personal exposures in terms of electric field strength, power density and transmitted energy.

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Chapter Summary

This chapter reviewed literature relevant to the study. The concept of radiation as either energy travelling as wave or energy was discussed. RF EM radiations are a very important part of the EM spectrum. Sources of RF exposure were grouped as extra-terrestrial natural, terrestrial natural, intentional man-made and unintentional man-made sources. Exposure pathways of humans to RF fields was grouped as personal, occupational and environmental exposure pathways. EM fields interact with living matter in one of the following methods: coupling to low-frequency electric fields, coupling to low-frequency magnetic fields and absorption of energy from electromagnetic fields. The most understood effect of RF field interaction with living tissue is thermal heating. Conclusion from epidemiological studies is that RF fields might be carcinogenic to humans. The popular and widely accepted benchmarks in the protection against the effects of RF on humans are the standards of the IEEE, ICNIRP guidelines and the FCC exposure guidelines. The interaction of EM radiation with living tissues at the cellular and molecular levels produces dielectric properties of biological media. Four basic equations describe these interactions and are collectively referred to as Maxwell's equations. Matters arising from the review of the related literature points to the fact that all the popular guidelines recommend limits with respect to both occupational and general population exposures but none considered the total amount of energy the human body extracts from the ambient field.

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CHAPTER THREE

RESEARCH METHODS

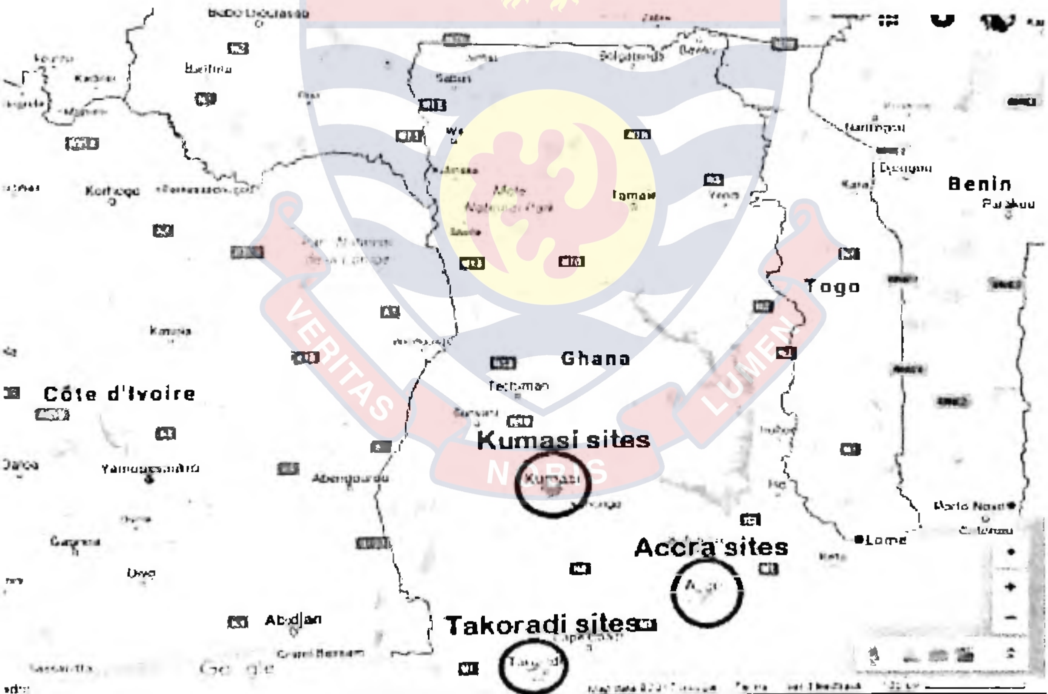
Introduction

This chapter provides the description of the equipment and methods employed for the study. Measurements include:

i) Electric field intensity at 10 locations each within three of Ghana's populous cities.

ii) The elevation of the 30 locations above sea level.

iii) The coordinates of the 30 locations within the three cities where measurements were taken. These locations are plotted in Figure 3, Figure 4, Figure 5 and Figure 6



Source: Google map, 2017

Figure 3: Location of Research Sites in Ghana

The study area is made up of commercial, residential, recreational, educational and health zones. The detailed site characteristics are found in Table A6 (in Appendix A). The uncertainty estimation technique has also been described.

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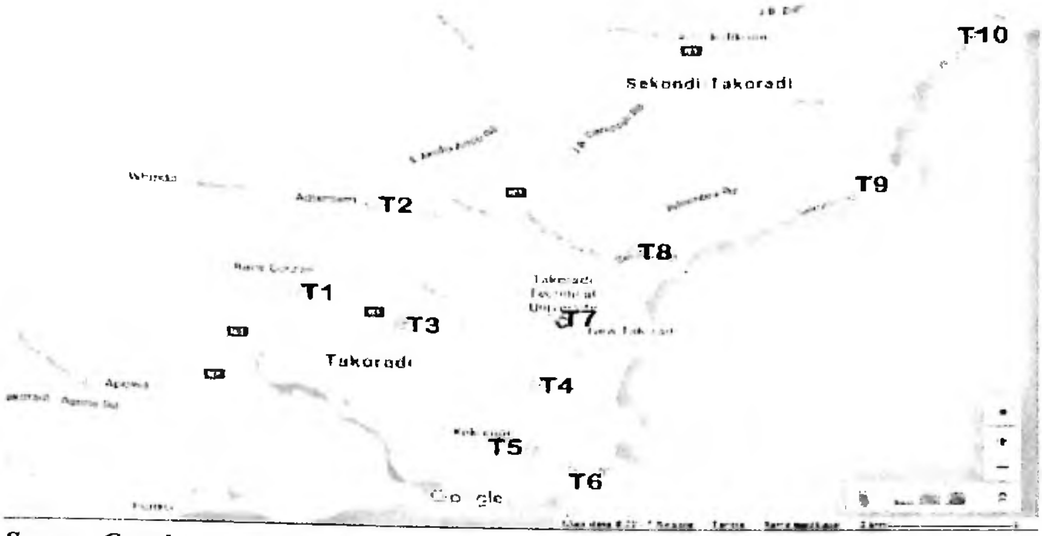
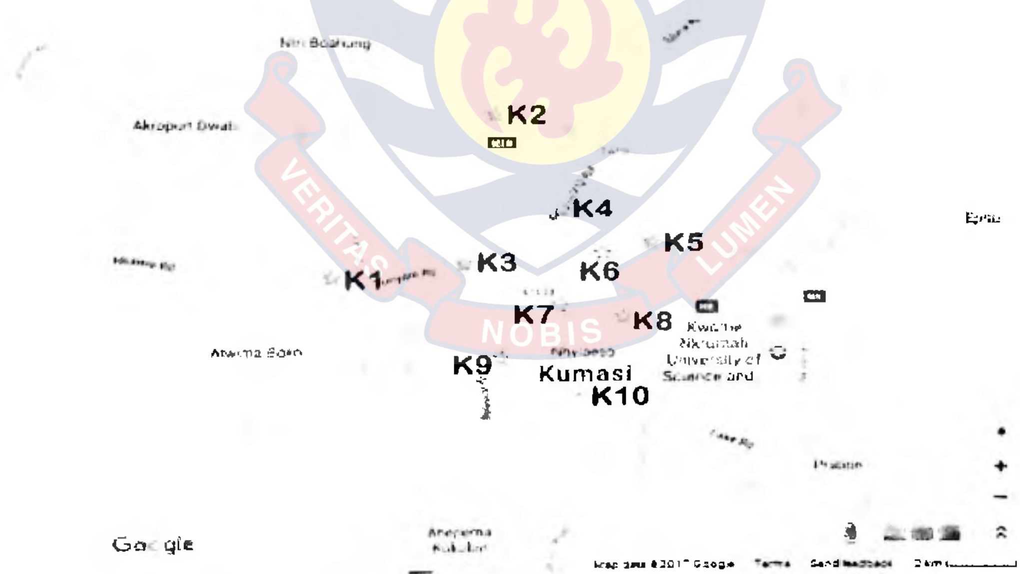


Source: Google map, 2017.

<u>Legend</u>

T1 •Galaxy Aben be bong
T2 •Anaji West Line
T3 •Lagos Town
T4 •Market Circle
T5 •Vienna City Roundabout
T6 •Takoradi Harbour
T7 •Takoradi Tech University
T8 •Effie Nkwanta Hospital
T9 •Fort Orange
T10 •Essipong

Figure 4: Map Showing Locations where Measurements were taken in Sekondi-Takoradi



Source: Google map, 2017.

<u>Legend</u>

K1 •UEW College of Technology
K2 •Bremang
K3 •Prempeh College
K4 •Kumasi Wesley Girls
K5 •Airport Roundabout
K6 •Manhyia
K7 •Adum
K8 •Baba Yara Stadium
K9 •Santasi Roundabout
K10 •Melcom

Figure 5: Map Showing Locations where Measurements were taken in Kumasi

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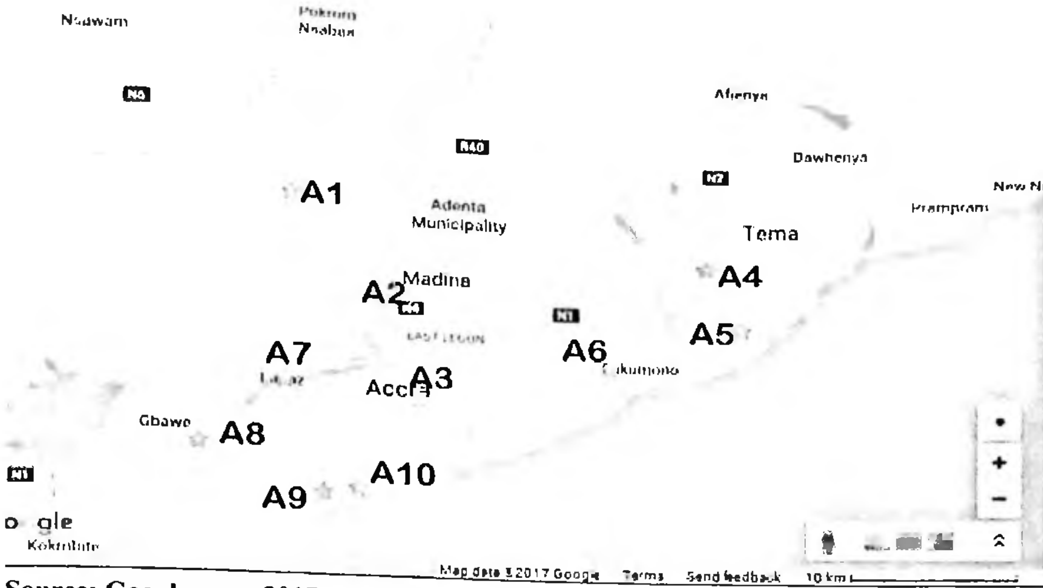

Source: Google map, 2017.

Legend

A1 •Comet Hills
A2 •University of Ghana
A3 •Airport Aviance
A4 •Tema Roundabout
A5 •Tema Community One
A6 •Sakumono Total Filling Station
A7 •Abeka Junction
A8 •McCarty Hill
A9 •Korle-Bu Teaching Hospital
A10 •Rawlings Park

Figure 6: Map showing Locations where Measurements were taken in Accra-Tema

Instrumentation

A spectrum analyser, Master Software, a Garmin Global Positioning System (GPS) system (Oregon®750 s/n: 4SQ011999), a log-periodic antenna with its accessories and a CORE™ i7 intel inside™ laptop computer was used to undertake the measurements. The GPS is a space-based satellite navigation system that provides location, and time information. This device works irrespective of weather conditions provided there is an un-obstructed Line-of-Sight with four or more GPS satellites placed above the earth. It also gives information such as Latitude and Longitude, and height of measurement locations above sea level. The spectrum analyser is an Anritsu Spectrum Master for RF and microwave handheld instruments, MS2722T with serial

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number 1338067 and App version V5.98. Its optimum operating range is within the range 9 kHz – 7.1 GHz. It is shown in Figure 7. The Anritsu log-periodic antenna model MP666A with serial number 6200849238 is sensitive and effective within the frequency range of 80 MHz to 2.690 GHz and works with RF cable of fixed balun load impedance of 50Ω. All the materials are available at the Health Physics and Instrumentation Centre of the Radiation Protection Institute within Ghana Atomic Energy Commission.

A laptop computer compatible with the Spectrum master was used to retrieve the stored data from the spectrum analyser and the installed Master Software aids in processing the raw data. The following software tools were also required in addition to the RF survey tools mentioned above;

- Master Software Tool (Version 2.21.4)
- Google Earth software (Version 9.81.1)
- Microsoft Office 2016

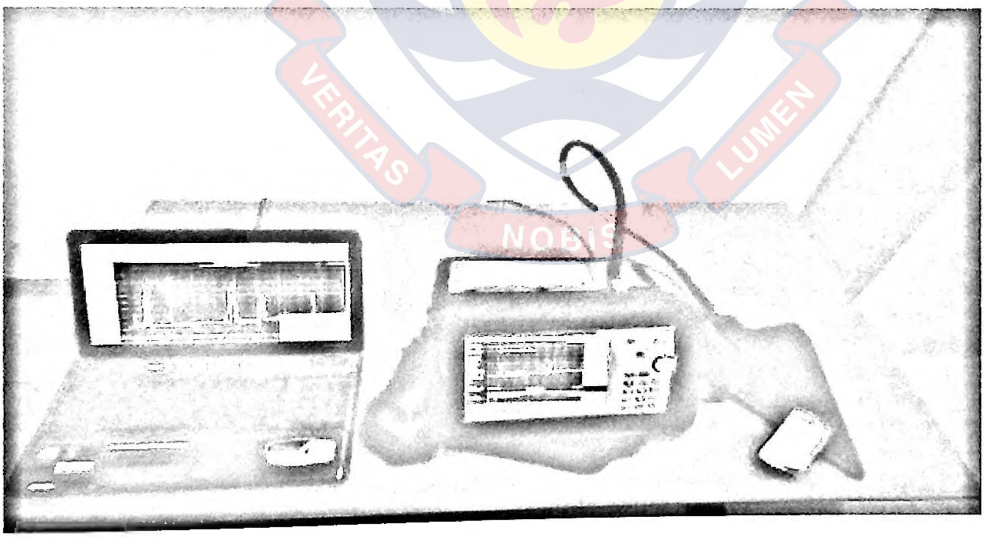

Figure 7: Anritsu Spectrum Master MS2721B with PC and Antenna

Methodology

Three main procedures were followed in the measurement process:

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- An initial desktop assessment using aerial photographs and street view from Google map software to determine likely measurement locations;
- A fast broadband scan of all possible signals in the vicinity of the base stations; and
- A final measurement at the confirmed locations.

Determination and Documentation of Test point(s).

Ten (10) different locations were appropriately selected in each of the following cities; Kumasi, Accra-Tema, and Sekondi-Takoradi. The selected sites cover, as much as possible, all network operators, technologies, geography and type of installations. The level of public concern, concentration of base stations in close proximity to each other and other special circumstances that may provide cause for community concern were also considered. Measurement locations within the cities were chosen so as to be as close as practically possible to at least three known intentional RF generators and or transmitters. Mobile phone base transceiver stations (BTSs) were given an overriding priority in the selection of these locations. These points were chosen to represent areas of highest levels of exposure to which a person might be subjected, considering the positions of transmitting antennas.

The measurements points were located in the far-field region, where plane-wave conditions were assumed, and lie within 300 m to 1000 m radius about the foot of the nearest intentional RF generator and or transmitter. In most instances, these intentional RF generators and or transmitters were BTSs. FM and TV stations were also used as reference intentional RF generator and or transmitter. The aptness of a location is fundamentally determined by the

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ability of researcher to access the areas expected to have the highest levels and good line of sight to at least three antenna systems at three different locations. These locations were found by a quick check whilst walking the streets surrounding the base station and using measuring equipment to scan and record the entire spectrum of interest; 87.5 MHz through to 2.6 GHz.

For repeatability of this work, GPS coordinates of the locations were taken using the Geo Explorer and recorded appropriately. Each of the sites was described in terms of elevation above sea level, weather conditions (cloudy, sunny etc.), and time of assessment. The locality was equally classified as either residential (High-density versus low-density residential) or commercial hub. The type of buildings within the immediate vicinity of the measurement site was recorded. The number of masts with line of sight with measuring antenna and located within 1km radius about the desired location was also of interest.

Survey Protocol

Radiofrequency emission levels were measured according to the protocols developed by the Commission for Communications Regulation (ComReg), the licensing authority for the use of the radio frequency spectrum in Ireland. The methodology incorporates many of the measurement methods and procedures outlined in Electronic Communications Committee (ECC) Recommendation (02)04 (ComReg 08/51, 2008). To provide a clear picture of the level of ambient emissions present at all selected survey locations, many alterations were made to the basic ECC recommended methodology. The most notable amongst them;

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- The application of correction factors to measured field strengths as a way of compensating for the limited spectrum analyser measurement bandwidths relating to wideband signals
- Frequency selective measurements were conducted in all cases
- "Two-axis" antenna was used for all frequency selective measurements

Measurement Set-up

The Anritsu log-periodic antenna was connected via a lead shielded RF cable of length 1 m to the Anritsu Spectrum Master MS2722T. The Spectrum master was booted and the appropriate parameters set up;

Bandwidth (BW) = 100 kHz

Minimum sweep time of 1 ms,

Input attenuation 10.0 dB

RBW of 1.0 MHz

VBW of 300.0 kHz

Trace mode as normal

Detection as peak.

Scale 10.0 $dB\mu Vm^{-1}$/div

The set-up was allowed five minutes to warm up and equilibrate with environmental conditions. The frequency range of interest was further sub divided into ten (10) bands after a quick scan at the selected locations.

At each location, a 6-minute time-averaged spatial measurements were made at four heights; 1.0 m, 1.5 m, 1.7 m and 2.0 m as shown in Figure 8. Two measurements were taken for each spatial height per frequency band as in

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Table 3 by flipping the antenna such that the log periodic elements are either vertically (labelled as X-axis) or horizontally (labelled as Y-axis) aligned.

Table 3- Frequency Bands Investigated

S/n	Frequency Bands	No of measurements
1	87.8 MHz – 2.6 GHz	8
2	87.5 MHz – 109 MHz	8
3	109 MHz – 400 MHz	8
4	400 MHz – 600 MHz	8
5	600 MHz – 800 MHz	8
6	800 MHz – 900 MHz	8
7	900 MHz – 1 GHz	8
8	1 GHz – 1.2 GHz	8
9	1.2 GHz – 1.7 GHz	8
10	1.7 GHz – 1.9 GHz	8
11	1.9 GHz – 2.6 GHz	8

The alternating of the antenna element positions was to help explore the small-scale variation and to reduce the chances of a local minima due to destructive interference skewing the results. Eighty-eight measurements were taken and logged into the spectrum master at each location. These data were taken at a period between 7:00 am to 4:00 pm at public access points.

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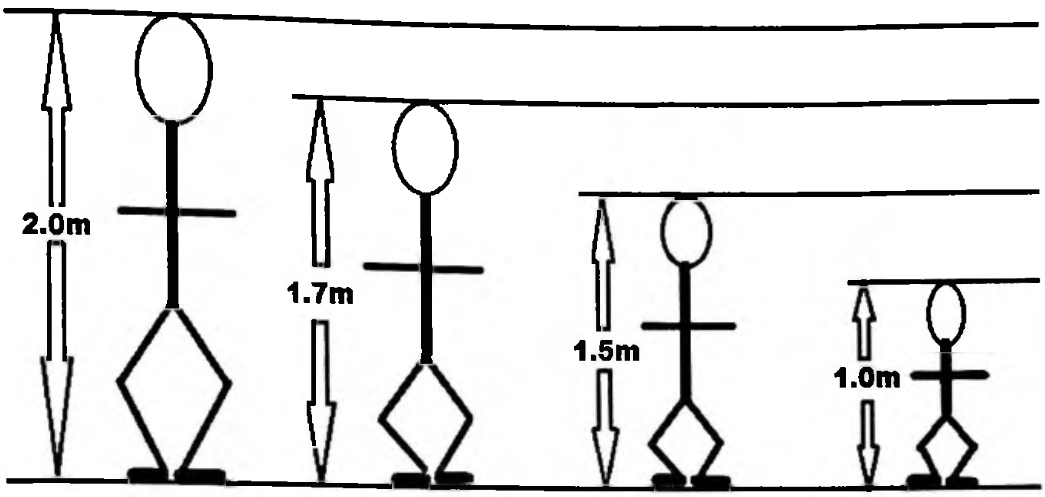

Figure 8: Spatial Measurement Heights

Most of the measurements were performed between 10:00 am - 1:00 pm, since data available at the offices of the telecommunication companies indicates that there is heavy traffic within the said period (Amoako, 2009). The schematic RF diagram of the frequency selective measurement of RF field is as shown in Figure 9.

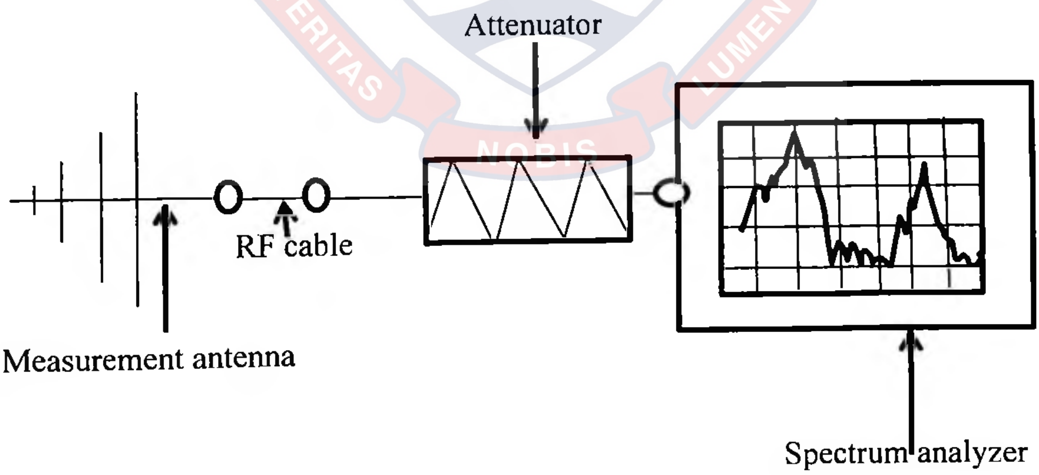

Figure 9: Diagram of a Frequency Selective Measurement of RF Field

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Determination of Field Strength

The highest peaks corresponding to the frequency of interest are marked using Master Software Tools installed on a personal computer (PC). These results were corrected for radiofrequency (RF) cable and antenna losses by selecting the appropriate antennas and factors from the spectrum analyzer library according to the following equation:

$$E_c\left(dB\mu\frac{V}{m}\right) = K\left(\frac{dB}{m}\right) + V_m(dB\mu V) + L(dB) \quad (34)$$

where $E_c\left(dB\mu\frac{V}{m}\right)$ is the corrected electric field strength for cable and antenna loses taking into consideration polarisation; $K\left(\frac{dB}{m}\right)$ is the antenna correction factor. $V_m(dB\mu V)$ is the receiver input voltage across 50 Ω balun, and L(dB) is the cable correction factor. The field strength level in (dBμV/m) was converted to E_i (V/m) for each measurement using the equation;

$$E_i\left(\frac{V}{m}\right) = 10^{\left\{\frac{E_c\left(dB\mu\frac{V}{m}\right)-120}{20}\right\}} \quad (35)$$

The time-averaged rms values of the electric field strength E_t, averaged over 6 min, can be obtained by using the following formula:

$$E_t = \left[\frac{1}{6}\sum_{i=1}^{n} E_i^2\, \Delta t_i\right]^{0.5} \quad (36)$$

where Δt_i is the time duration, in minutes, of the i^{th} time period and n is the number of time periods within 6 min. Most signals employed in radio communication demonstrate a variation with time due to modulation of mobile telecommunication system or due to traffic. Picture content of analogue TV systems and duty cycle of radar equally produce this variation.

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Determination of Spatial Averaged Field Strength

A fundamental aspect of the exposure guidelines is that they apply to power densities or the squares of the electric and magnetic field strengths that are spatially averaged over the body dimensions (FCC, 1997). This is because multi-path reflections can create non-uniform field distributions. Spatially averaged RF field levels most accurately relate to estimating the whole-body averaged specific absorption rate (SAR) that will result from the exposure. This means that local values of exposures that exceed the stated MPEs do not imply non-compliance if the spatial average of RF fields over the body does not exceed the MPEs (FCC, 1997). The spatial average electric field strength E_{av} for each location was determined using equation 37 below;

$$E_{av} = \left[\frac{1}{n}\sum_{i=1}^{n} E_i^2\right]^{0.5} \quad (37)$$

Determination of Far-field Power Density

Assuming a far-field condition, the power density S (W/m^2), at each location was calculated employing equation 38 (FCC, 1997).

$$S = \frac{E_{av}{}^2}{376.7303} \quad (38)$$

where E_{av} = spatial averaged electric field strength (V/m) measured and 376.7303 Ω is characteristic impedance of free-space (η_o).

Uncertainty Estimation.

The combined spatial average uncertainty $U_c(E)$ for the electric field measurements was evaluated taking into consideration each of the various sources of uncertainty in the measurements.. The larger the number of

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measurements, the more closely the distribution approaches the Gaussian normal distribution. The combined spatial average uncertainty associated with the ith spatial point approached a normal probability distribution as shown in Table 4. The estimated total uncertainty in the measurement included the estimation of the arithmetic mean values of the electric field strength at each spatial point. The spatial averaged electric field values were estimated using equation 37. The mean value of the square of the deviations of the individual measurements from the mean called Variance was calculated. The normal statistical method of finding out the standard deviation which is equal to the standard uncertainty of that particular quantity was employed. This was done by taking the square root of the variance. The partial derivatives c_i (sensitivity coefficients) of the mean values were calculated according to equation 37. The effective degrees of freedom were calculated. The level of confidence (95.45%) was chosen and the coverage factor k (probability that the set of true quantity values of a measurand is contained within specified coverage interval.) was determined from the Students t factor table.

The combined standard uncertainty estimation of each frequency sample involves the evaluation of root-mean-square value of all the partial standard uncertainties that affect the electric field values according to the method of the International Bureau of Weight and Measures (BIPM) (European Telecommunications Standards Institute [ETSI], 2001) using the following equation:

$$u_i = \sqrt{\sum_j u_{TA,j}^2 + \sum_m u_{TB,m}^2} \tag{39}$$

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where $u_{TA,j}$ is the standard uncertainty accounting for the *j*th type-A uncertainty contributor (estimated by statistical method), and $u_{TB,m}$ is the standard uncertainty accounting for the *m*th type -B uncertainty contributor (estimated using non-statistical analysis of a series of observation).

Table 4- Estimation of Expanded Uncertainty for Measurement of Electric Field Strength

Uncertainty sources	Type	Probability distribution	Divisor	c_i	$u(x_i)$%	V_i
Spectrum Analyzer						
1 Amplitude accuracy	B	Rectangular	1.73	1	--	∞
2 Resolution Bandwidth	B	Normal	2.00	1	--	∞
Device-Under-Test						
3 Mismatch (Analyzer and Antenna)	B	U-shape	1.41	1	--	∞
4 Antenna calibration factors	B	Normal	2.00	1	--	∞
5 Cable correction factor	B	Rectangular	1.73	1	--	∞
6 Measurement Repeatability	A	Normal	1.00	1	--	n-1
Measurement uncertainty						
Combined uncertainty (%)		$u_c(E) = \sqrt{\sum_{i=1}^{n}(C_i * u(x_i))^2}$				
Effective degrees of freedom		$V_{eff} = \frac{(u_c(E))^4}{\sum_{i=1}^{n}(u(x_i))^4/V_i}$				
Desired coverage probability		P				
Respective coverage factor		k				
Expanded uncertainty (%)		$U = \pm k * u_c(E)$				

When a large number of measurements is averaged to obtain the best estimate, the uncertainty due to repeatability of measurement can be neglected, making. $u_{TA,j} = 0$. The combined standard uncertainty $u(E_{av})$ of E_{av} then becomes

$$u_i = \sqrt{\sum_{m=1}^{uc} u_{TB,m}^2} = \sqrt{\sum_{m=1}^{uc}(c_{m,i} * u(x_{m,i}))^2} \quad (40)$$

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The uncertainty associated with power density was estimated assuming far-field conditions using the following equation:

$$u(S) = 2u(E_{av}) \tag{45}$$

Estimation of Energy during RF-Tissue Interaction

Electric and magnetic fields store energy. Therefore, energy is also carried by the electromagnetic waves that consist of both fields. When electromagnetic waves encounter the human body, the wavelength decreases, electrical currents are generated and wave reflection/refraction may develop at tissue interfaces. When a far-field plane-wave is incident on a small volume of human body of area A and thickness d_Z as shown in Figure 10, the total energy, dU_i, incident on the volume element is derived from

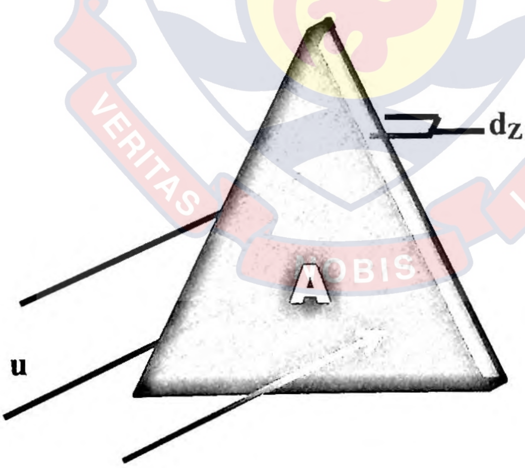

Figure 10: Plane Electromagnetic Wave passing through a Human Volume Element

$$dU_i = uAd_Z \tag{46}$$

$$dU_i = (u_E + u_B)Ad_Z \tag{47}$$

$$dU_i = \frac{1}{2}\left(\varepsilon_0 E^2 + \frac{B^2}{\mu_0}\right)Ad_Z \tag{48}$$

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where $u_E = \frac{1}{2}\varepsilon_0 E^2$ is the electric field energy density and $u_B = \frac{B^2}{2\mu_0}$ is the magnetic field energy density. The time taken by the plane-wave to move through the volume element is thus given by $d_t = \frac{d_z}{c}$ with c as the speed of light. Equation 48 becomes

$$dU_i = \frac{c}{2}\left(\varepsilon_0 E^2 + \frac{B^2}{\mu_0}\right) A d_t \tag{49}$$

From $E = cB$ and $c = \frac{1}{\sqrt{\mu_0 \varepsilon_0}}$, we obtain the following equations

$$B = \frac{E}{c} \tag{50}$$

$$\mu_0 = \frac{1}{c^2 \varepsilon_0} \tag{51}$$

Substituting equations 50 and 51 into 49 we obtain

$$dU_i = \frac{c}{2}\left(\varepsilon_0 E^2 + \left(\frac{E^2}{c^2}\right) c^2 \varepsilon_0\right) A d_t \tag{52}$$

$$dU_i = \frac{c}{2}(\varepsilon_0 E^2 + E^2 \varepsilon_0) A d_t \tag{53}$$

$$dU_i = (c\varepsilon_0 E^2) A d_t \tag{54}$$

Taking the integral of both sides of equation 54 one obtains the total energy incident on the defined area, U, imparted to the volume element as a result of its presence in the field as

$$U_i(t) = c\varepsilon_0 E^2 A \int_a^b d_t \tag{55}$$

At the skin-air interface during the interaction, part of the incident energy is reflected back into the air medium whilst part is transmitted across the air-tissue boundary.

The energy balance equation for the interactions is given as;

$$U_i(t) - U_r(t) = U_t(t) \tag{56}$$

Equation 56 can be written in terms of equation 55 as

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$$c\varepsilon_1 {E_i}^2 A \int_a^b d_t - c\varepsilon_1 {E_r}^2 A \int_a^b d_t = c\varepsilon_2 {E_t}^2 A \int_a^b d_t \qquad (57)$$

where

$U_i(t) = c\varepsilon_1 {E_i}^2 A \int_a^b d_t$ is the incident energy,

$U_r(t) = c\varepsilon_1 {E_r}^2 A \int_a^b d_t$ is the reflected energy and

$U_t(t) = c\varepsilon_2 {E_t}^2 A \int_a^b d_t$ is the transmitted component of the ambient energy and are shown pictorially in Figure 11. E_t is the electric field intensity within the tissue. Some energy is extracted from the transmitted electric field and subsequently absorbed by the biological tissue as the transmitted component propagates in the tissue medium. The continuous absorption as the waves advances in the tissue medium results in the progressive reduction in the wave's power density (Michaelson & Lin, 1987).

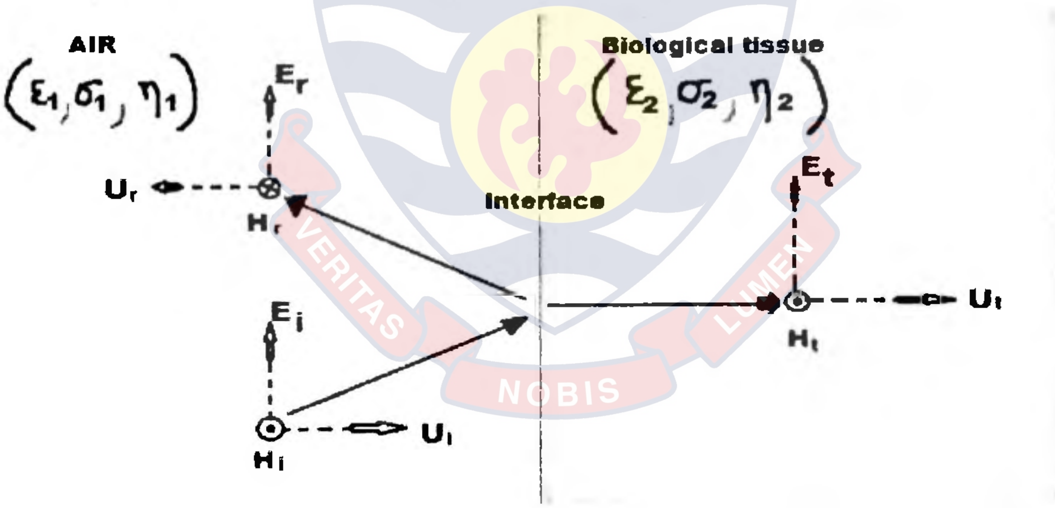

Figure 11: Plane-wave Impinging on a Biological Tissue.

In Figure 17, the properties of Air and biological tissue media are respectively $\varepsilon_1, \sigma_1, \eta_1$ *and* $\varepsilon_2, \sigma_2, \eta_2$ with ε_1 as permittivity, σ_1 as conductivity and η_1 as intrinsic impedance of the air medium whilst $\varepsilon_2, \sigma_2,$ and η_2 are similar quantities for the tissue medium. From definition, reflection coefficient

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is the ratio of reflected wave and incident wave. The reflection coefficients for E and H are given in relation (58) and (59) respectively as,

$$\Gamma_E = \frac{E_r}{E_i} \tag{58}$$

$$\Gamma_H = \frac{H_r}{H_i} \tag{59}$$

where

E_i is incident electric field, E_r is reflected electric field, H_i is incident magnetic field, H_r is reflected magnetic field, Γ_E is the Reflection coefficient for H and Γ_E is the Reflection coefficient for E. The Transmission coefficients for E (T_E) and H (T_H) are given in equations 60 and 61 as

$$T_E = \frac{E_t}{E_i} \tag{60}$$

$$T_H = \frac{H_t}{H_i} \tag{61}$$

From definition, intrinsic impedance is given as η = E/H. Therefore

$$E_i = \eta_1 H_i \tag{62}$$

$$E_r = -\eta_1 H_r \tag{63}$$

$$E_t = \eta_2 H_t \tag{64}$$

The tangential components of both E and H are continuous at the interface giving us

$$E_i + E_r = E_t \tag{65}$$

$$H_i + H_r = H_t \tag{66}$$

where E_t and H_t are the tangential components of E and H respectively. From equations 63 and 64

$$E_i - E_r = \eta_1 H_i + \eta_1 H_r = \eta_1 (H_i + H_r) = \eta_1 H_t \tag{67}$$

From equation 64 Ht = E_t / η_2. Substituting this into equation 67, we obtain

$$\frac{\eta_1}{\eta_2} E_t = E_i - E_r \tag{68}$$

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Substituting equation 65 into 68, we get

$$\frac{\eta_1}{\eta_2}(E_i + E_r) = (E_i - E_r) \tag{69}$$

$$\eta_2(E_i - E_r) = \eta_1(E_i + E_r) \tag{70}$$

$$E_r(\eta_2 + \eta_1) = E_i(\eta_2 - \eta_1) \tag{71}$$

$$\frac{E_r}{E_i} = \frac{\eta_2 - \eta_1}{\eta_2 + \eta_1} = \Gamma_E \tag{72}$$

where Γ_E is the reflection coefficient.

Dividing through equation 65 by E_i we get

$$\frac{E_t}{E_i} = 1 + \frac{E_r}{E_i} \tag{73}$$

Substituting equation 72 into 73, we obtain

$$\frac{E_t}{E_i} = 1 + \frac{\eta_2 - \eta_1}{\eta_2 + \eta_1} \tag{74}$$

$$\frac{E_t}{E_i} = T_E = \frac{2\eta_2}{\eta_2 + \eta_1} \tag{75}$$

where T_E is the transmission coefficient. Therefore, equation 57 becomes

$$c\varepsilon_1 E_i^{\,2} A \int_a^b d_t - c\varepsilon_1(\Gamma_E E_i)^2 A \int_a^b d_t = c\varepsilon_2 (T_E E_i)^2 A \int_a^b d_t \tag{76}$$

In this work, equation 72 was used to calculate the reflection coefficient whilst equation 75 was employed to calculate the transmission coefficient at the air-tissue interphase in terms of the intrinsic impedances of the two media. Equation 76 was used to estimate the ambient RF energy and the energy transmitted across the air-tissue boundary into the various tissues.

Chapter Summary

The study covered three cities in Ghana: Accra-Tema, Sekondi-Takoradi and Kumasi. The cities that have the largest population of BTSs, FM radio and TV stations. Measurement were made at 10 locations within each

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city using an Anritsu spectrum analyser with its compatible Master software and a log-periodic antenna with its accessories. A GPS system provided the coordinates of the locations. The measurement locations were selected in order to cover, as much as possible, all network operators. The locations as well have a direct line of sight with at least three antenna systems. All measurements were made in the far field regions of the antennas. The survey protocol used in this study are outlined in ECC recommendations with some notable enhancements such as usage of correction factors to compensate for limited spectrum analyser bandwidths and making frequency selective measurements in all cases. The measured electric field strengths were converted to the standard unit using the appropriate relations. In each location spatial averaged field strength levels were calculated and their equivalent far-field power density determined. The uncertainty associated with the measurements was estimated using the method of the International Bureau of Weight and Measures (BIPM) (European Telecommunications Standards Institute [ETSI], 2001). The ambient RF energy and the energy transmitted across the air-tissue boundary into the various tissues during RF interaction with living tissue was estimated for the tissues of interest.

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CHAPTER FOUR

RESULTS AND DISCUSSION

Introduction

This chapter discusses the results obtained from the study. The result includes ambient electric field levels measurements and computation as a result of physical interaction of the electric field with human tissue. There are two headline results reported for each location. The first headline value is the highest measured level of RF EME from all frequencies present at the locations. Fields at a particular spatial height and frequency (E_x and E_y) were resolved to give the time-average electric fields. The time-averaged electric fields at the 4 spatial heights were, in turn, resolved to give the spatial average plane-wave electric fields for each frequency. Electric fields within a specific frequency band were resolved to produce "frequency-band" electric fields or measured electric fields. Within each frequency band, electric field strengths at the 4 spatial heights were averaged to give the spatial average plane-wave electric field for the location. The second headline values are the estimated levels of RF EME absorbed by some body tissues of interest.

Electric Field Trend at Kumasi Sites

Baba Yara Stadium

Results indicate that electric field distribution at the point of interest varied with both height and antenna orientation. Relatively high values were obtained for antenna orientations that aligned antenna elements in the vertical plane. At a height of 2.0 m above the floor, high electric field values were obtained within 88.7 MHz – 440 MHz band. In Ghana this band is allocated

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for Broadcasting, Maritime Mobile, Radionavigation, Meteorological Aids, Aeronautical Mobile, and Amateur-Satellite Space Operation (NCA, 2003).

Figure 11 shows a plot of resolved spatial E-fields for the various orientations of the antenna elements, that is, X-axis and Y-axis at 2.0 m, 1.7 m, 1.5 m, and 1.0 m against the various frequency bands investigated. The highest E-field value of 0.3511 ± 0.05 V/m was obtained at 2.0 m for frequency of 224.3 MHz. Sources radiating at 92.1 MHz and 92.9 MHz produced an electric field level of 0.20 ± 0.03 V/m and 0.106 ± 0.02 V/m respectively at this selected location. Similar values were gotten for spatial heights of 1.7 m, 1.5 m and 1.0 m.

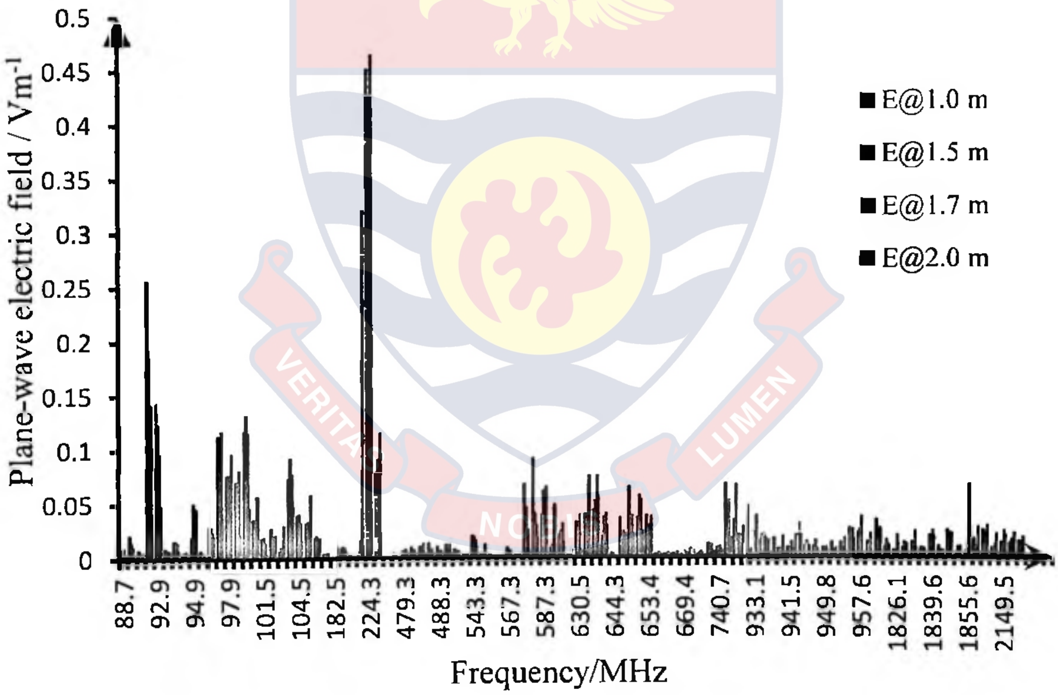

Figure 12: A plot of Time-averaged E-fields at 1.0 m, 1.5 m, 1.7 m, and 2.0 m at Baba Yara Stadium, Amakom

For 1.7 m the highest measured value of the electric field occurred at 224.3 MHz as 0.3385 ± 0.05 V/m when the antenna elements were vertically orientated in the Y-axis direction. At 1.5 m and 1.0 m, the highest electric field was determined to be 0.2198 ± 0.03 V/m and 0.3388 ± 0.05 V/m, respectively

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and all with the stacked antenna elements aligned in the vertical Y-axis direction.

After spatially averaging the resolved electric field values at the four spatial heights, the location Baba Yara stadium, Amakom recorded a range of 30.29 ± 4.36 mV/m to 579.41 ± 83.44 mV/m. The least spatial averaged plane-wave electric field was determined within the UMTS(WCDMA/3G) band at a height of 1.7 m whilst the maximum electric field was determined within the VHF TV at 1.0 m. The highest power density calculated for this location was 557.01 ± 80.32 mWm^{-2}. A total of 103 sources were detected at this location. The plot of the spatial average plane-wave electric field strengths against their corresponding frequencies is shown in Figure 13. The estimated total exposure quotients for this location was 4.20E-04 ± 6.06E-06. The summary of numerical results for this location is shown in Table A7 (in appendix A). The site is compliant with ICNIRP recommended levels.

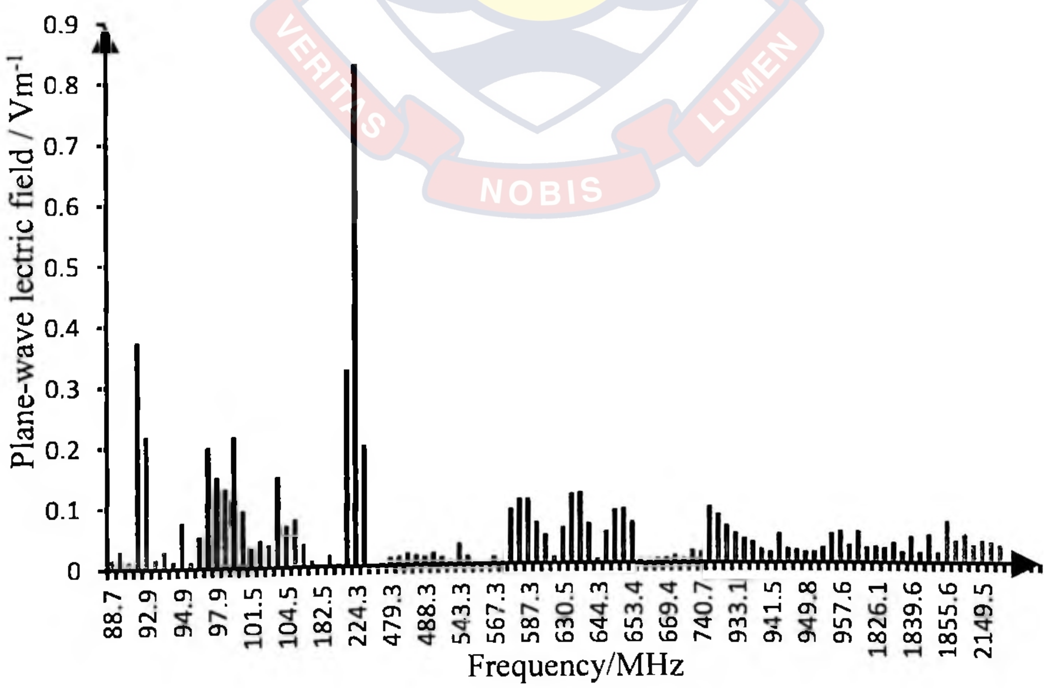

Figure 13: A Plot of E (spatial average) against Frequency for Baba Yara Stadium, Amakom.

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Melcom

The results indicate that the field strength at this location varied significantly with height and antenna element orientation. The electric field strength contributions came from varied sources. The highest field levels were due to FM radio transmissions. Relatively high contributions were detected at spatial heights of 1.0 m and 1.5 m. Time-averaged electric field strengths at the four spatial heights were plotted in Figure 14. The three predominantly high electric field strengths occurred at VHF (Band II and III) and UHF bands. These frequencies are used in the transmission of FM radio, analogue /digital TV and mobile telephony. At a spatial height of 1.5 m, the highest field level of 117.29 ± 16.71 mVm^{-1} was determined. This field was due to transmissions at 97.1 MHz. Another transmission at 229.6 MHz was responsible for the second highest field strength of 116.25 ± 17.23 mVm^{-1} at 1.0 m above the ground. Significant field levels were equally present at other frequencies for all the four spatial heights.

The four electric field strength levels at the four spatial heights were spatially averaged and plotted against frequency in Figure 15. The levels ranged from a high of 232.95 ± 33.20 mV/m through to a minimum of 54.07 ± 7.70 mV/m. The highest power density calculated for this location was 143.94 ± 20.51 μWm^{-2}. A total of 103 sources were detected at this location giving rise to an accumulated power density of 623.23 ± 88.81 μWm^{-2}. The power density due to each frequency complied with ICNIRP reference levels and the location as a whole equally complied as the total exposure quotient was determined to be 0.000107 representing 0.01% of the limit of unity. In

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Table A8 (in appendix A) the summary of the numerical results for this location were displayed.

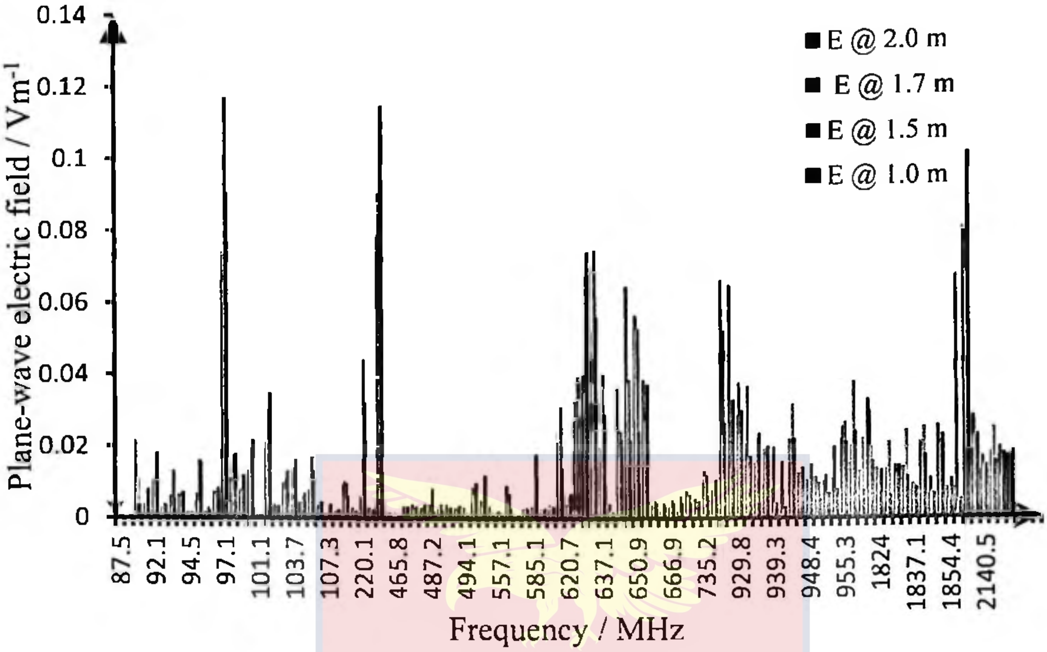

Figure 14: A Plot of Time-averaged E-fields at 1.0 m, 1.5 m, 1.7 m, and 2.0 m at Melcom

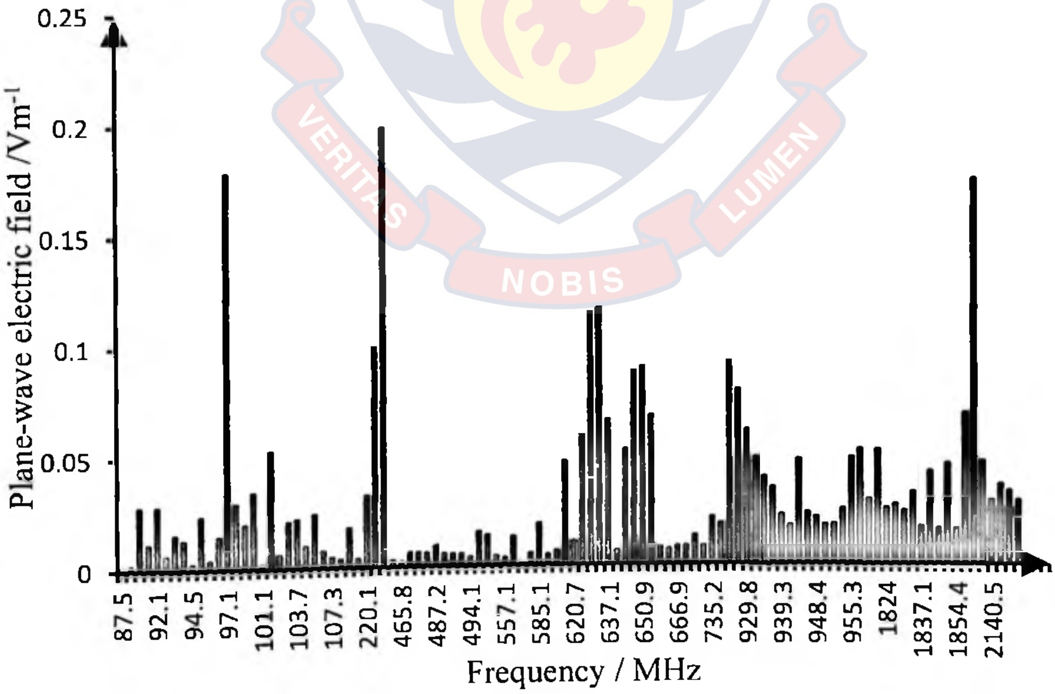

Figure 15: A Plot of E (spatial average) against Frequency for Melcom

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Santasi Roundabout

Results from the analysis of measurements show no clear relationship between electric field strength and spatial height. Most of the relative high field levels occurred at 1.5 m above ground level, other heights equally recorded high values. These values were independent of orientation of the stacked antenna elements. The time-averaged electric field strengths for each frequency at the four spatial heights shows that the highest field occurred at a spatial height of 2.0 m. The highest of 370.51 ± 58.80 mVm^{-1} due to transmissions at 926.9 MHz occurred at UHF band. Figure 16 shows the plotted field levels for each frequency at the four spatial heights.

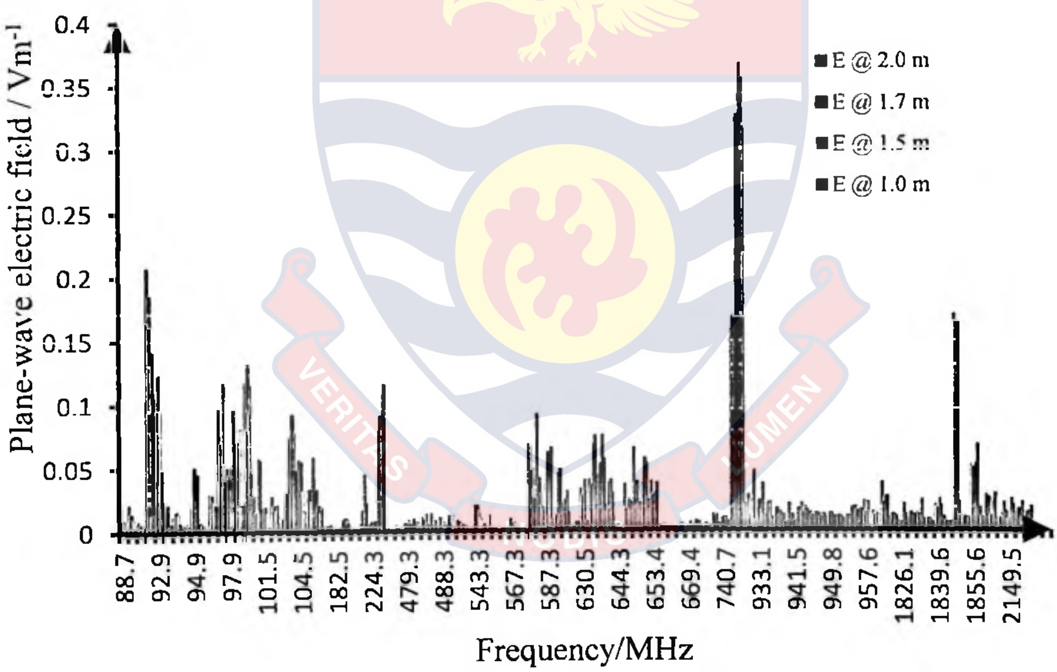

Figure 16: A Plot of Time-averaged E-fields at 1.0 m, 1.5 m, 1.7 m, and 2.0 m at Santansi Roundabout.

The spatial average plane-wave electric field levels were plotted against their source frequencies in Figure 17. The frequency, 926.9 MHz produced the strongest field with a magnitude of 609.32 ± 86.83 mVm^{-1} at

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UHF band. The next strongest field of 436.63 ± 62.22 mVm^{-1} originated from 925.1 MHz. FM radio signals produced significant field levels.

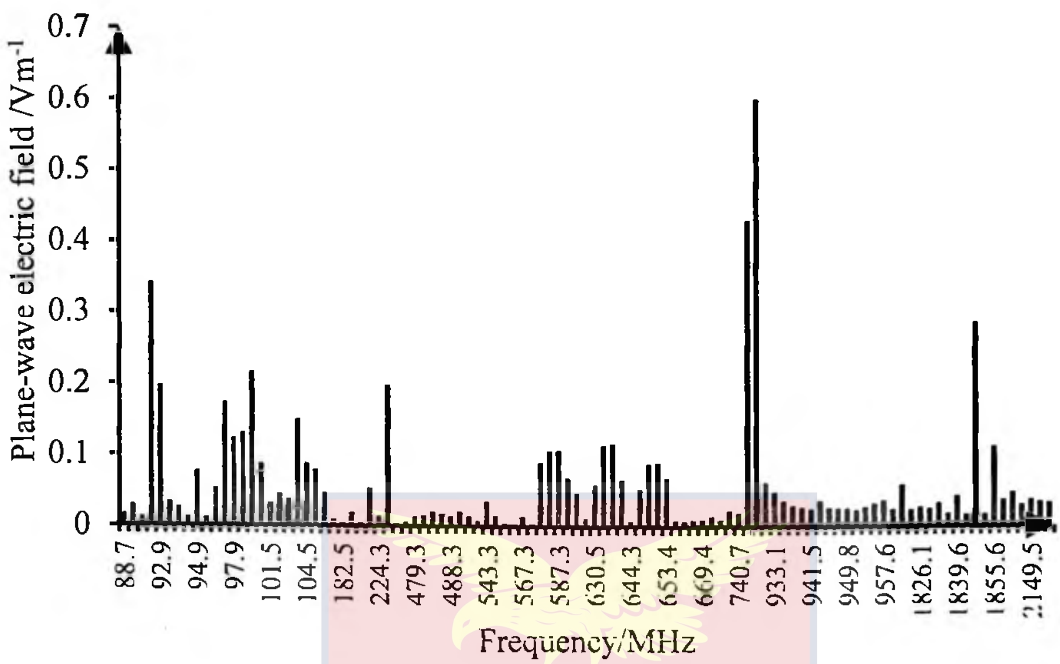

Figure 17: A Plot of E (spatial average) against Frequency for Santansi Roundabout

The numerical results for the various frequency bands are shown in Table A9 (in Appendix A). Relatively high field contributions came from GSM 900, FM broadcast, UHF and VHF TVs. Each frequency band recorded their highest plane-wave electric field strengths at different spatial heights. The maximum field per band came from GSM 900 at 2.0 m above ground with a value of 375.61 ± 53.49 Vm^{-1}. The highest power density was 374.23 ± 53.29 μWm^{-2}. With a total exposure quotient of 0.000211 representing about 0.02% of the limit of unity, the site complied with ICNIRP recommended levels.

Bremang

The results here did not exhibit a significantly variation of electric field with height and antenna element orientations. Variations occurred randomly.

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The electric field strengths contributions here came from varied sources. The predominantly high field levels were due to transmissions in the UHF bands. Relatively high contributions were detected at spatial heights of 1.5 m and 1.7 m above the ground level with numerical values of 244.21 ± 34.68 mVm^{-1} and 170.14 ± 24.16 mVm^{-1}. These fields were due to emissions from 925.1 MHz and 926.9 MHz. The difference between the highest detected field strength and the lowest at 925.1 MHz is 0.158. At 926.9 MHz the lowest field strength was 20.9 ± 2.97 mVm^{-1}. The Time-averaged electric field strengths at the four spatial heights are plotted in Figure 18. Plane-wave electric fields from FM transmissions were very low with most of them below 10.9 mVm^{-1}. Significant field levels were equally present at other frequencies for all the four spatial heights.

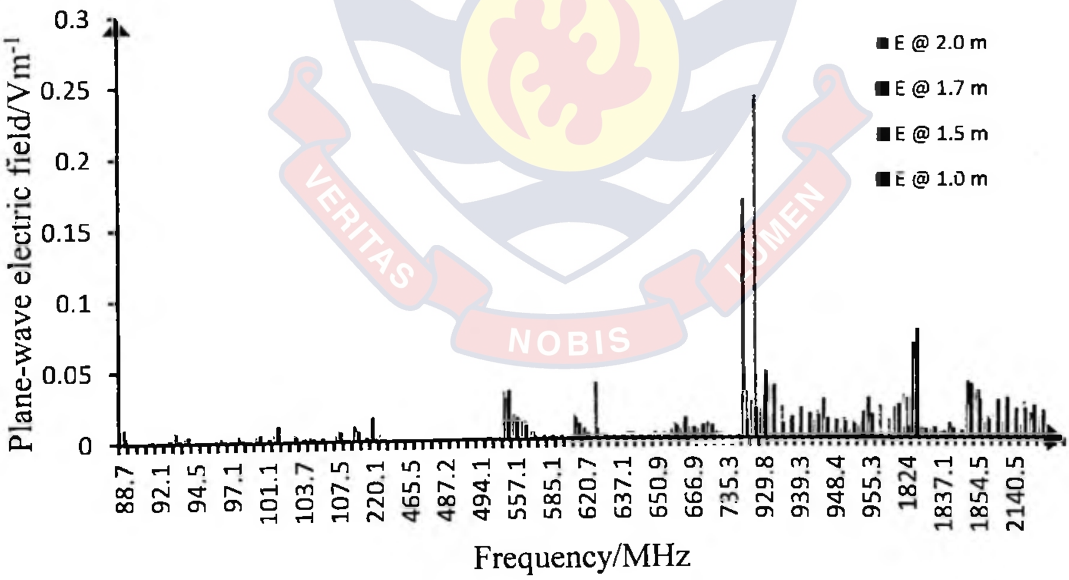

Figure 18: A Plot of Time-averaged E-fields at 1.0 m, 1.5 m, 1.7 m, and 2.0 m at Bremang

The spatial averaged electric field levels at the four spatial heights were plotted against frequency in Figure 19. The highest plane-wave electric field per frequency to which someone is likely to be exposed at this location

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was determined to be 247.1 ± 35.09 mVm^{-1} at 926.9 MHz. The location complied with ICNIRP levels for general public exposure in terms of exposure to individual frequencies.

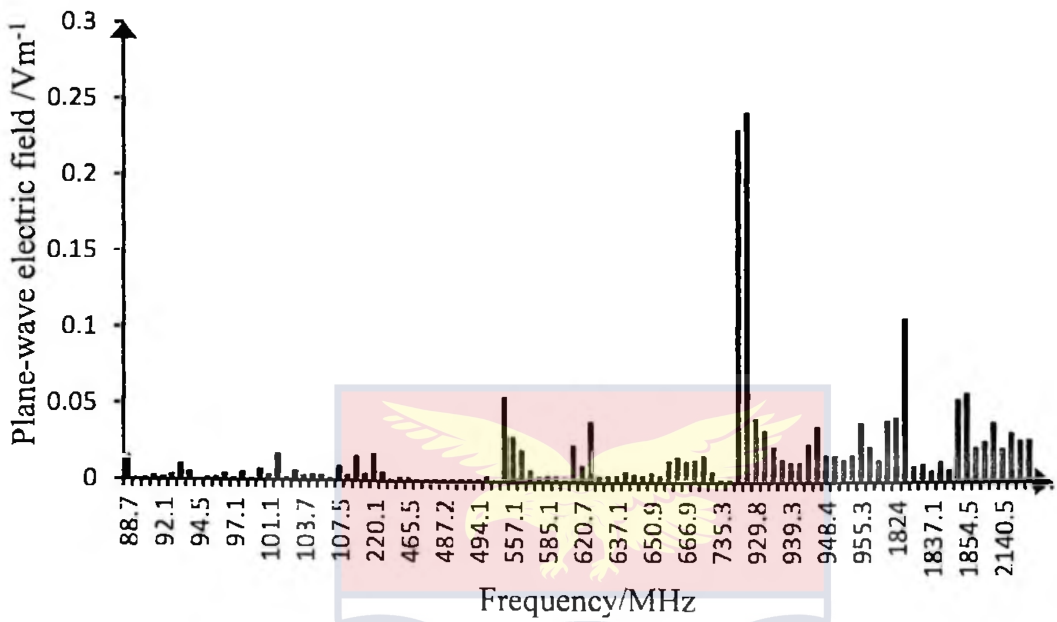

Figure 19: A Plot of E (spatial average) against Frequency for Bremang.

Table A10 (in appendix A) shows a summary of the numerical results for the frequency bands investigated at Bremang. The highest plane-wave electric field levels were obtained within the GSM 900 band. The fields at this location were largely very low compared with values from other locations within the sample size. Within FM broadcast, UHF TV and GSM 900 bands, the highest field levels were obtained at 1.5 m above ground level. The highest frequency band electric field strength was estimated at 1.5 m as 253.31 ± 36.07 mVm^{-1} within the GSM 900 band with an associated power density of 170.20 ± 24.24 $\mu W/m^2$. The site complied with the recommended ICNIRP reference levels for public exposure for each frequency band. The total exposure quotient for this location was 0.000044, about 0.004% of the limit of unity.

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Kumasi Wesley Girls High

The results from analysis of data obtained here show that the levels of electric fields are greatest when the antenna elements were aligned with the vertical plane (Y-axis). Figure 20 shows how the fields varied with antenna elements orientations in the vertical and horizontal planes at a spatial height of 2.0 m.

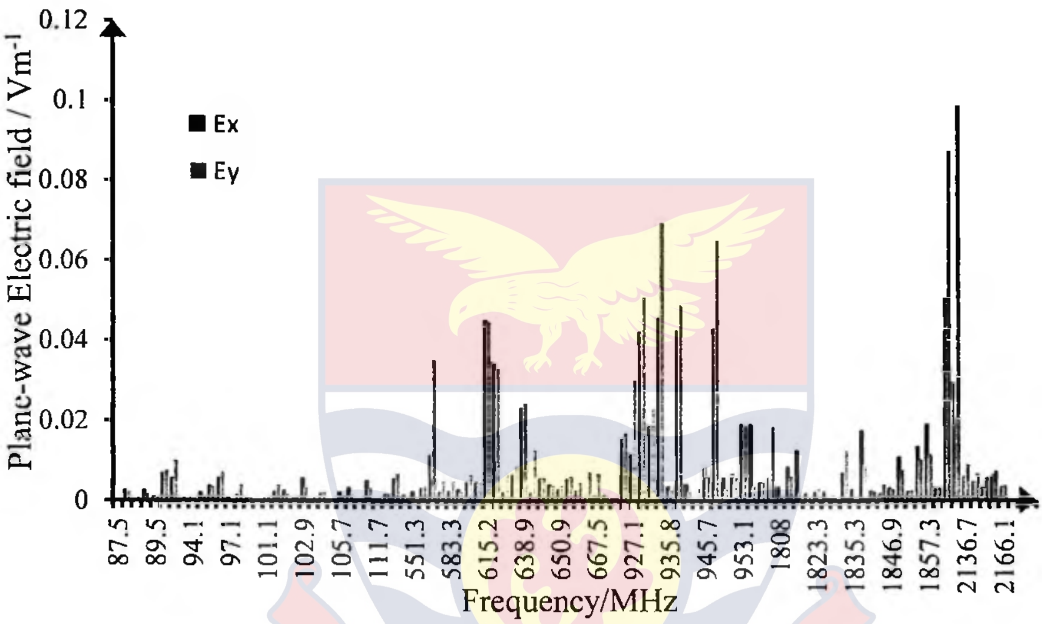

Figure 20: Variation of Electric Field with Antenna Element Orientations at 2.0 m at Kumasi Wesley Girls High

The fields *Ex* and *Ey* were resolved for the four spatial heights per each frequency investigated and plotted in Figure 21. The results did not exhibit a unique trend of variation of electric field with height. However, high field levels occurred for different frequencies at different heights. The highest resolved field of 159.67 ± 22.99 mVm^{-1} occurred at 615.3 MHz at a height of 1.7 m. Comparatively, plane-wave electric fields due to FM radio transmissions were lower than those from transmission above 500 MHz.

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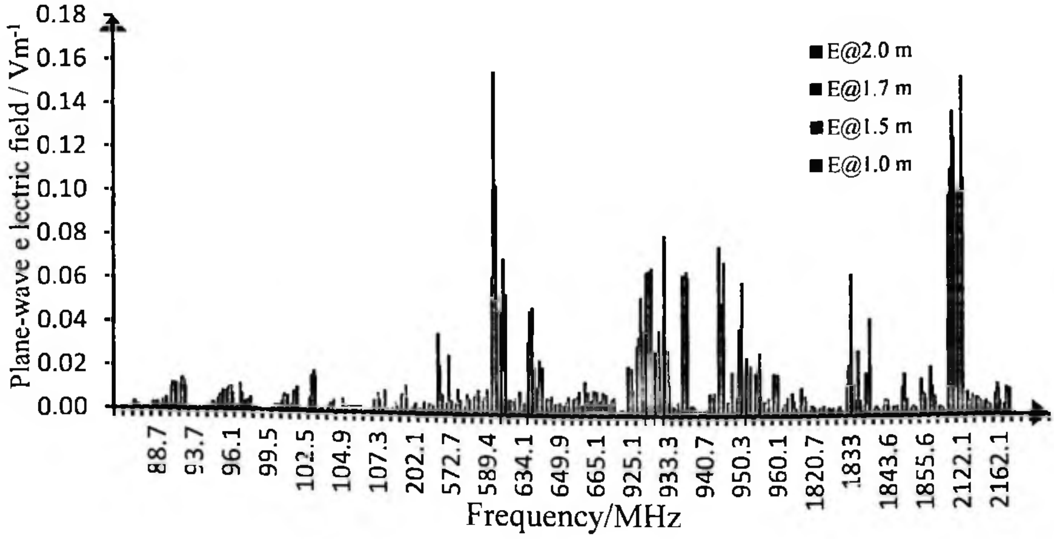

Figure 21: A Plot of Time-averaged E-fields at 1.0 m, 1.5 m, 1.7 m, and 2.0 m at Kumasi Wesley Girls High

The electric fields at the four spatial heights were spatially averaged to obtain a single electric field value for each frequency. The highest spatial averaged electric field strength obtained for this location was 245.21 mVm^{-1} at 2117.7 MHz closely followed by 205.28 mVm^{-1} at 615.1 MHz. The plane-wave spatial average field strengths were plotted in Figure 22. The electric field strength levels per individual frequencies complied with the recommended ICNIRP levels.

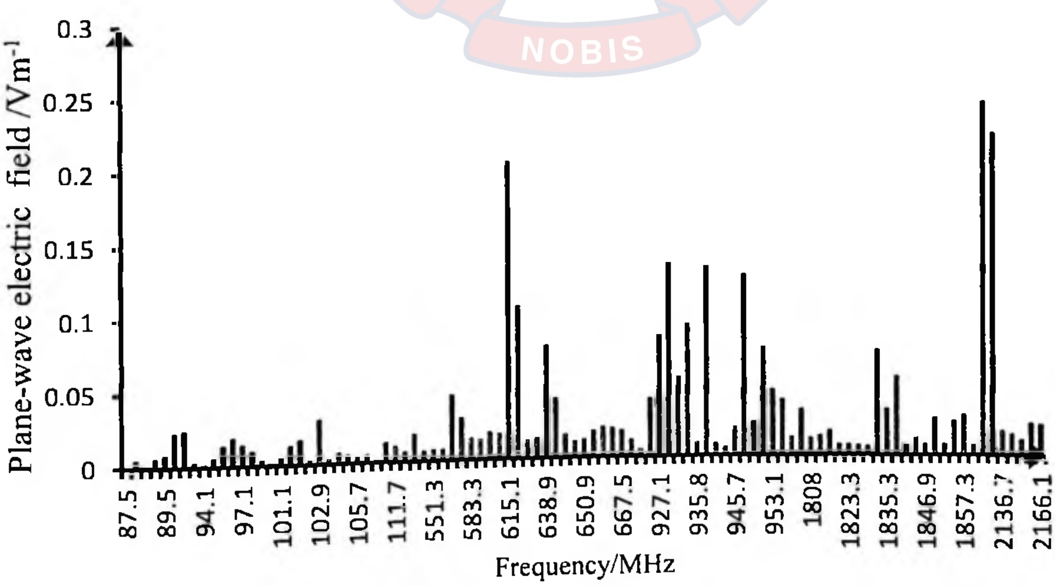

Figure 22: A Plot of E (spatial average) against Frequency for Kumasi Wesley Girls High

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Table A11 (in Appendix A) shows a summary of the numerical results for Kumasi Wesley Girls High location per the frequency bands investigated. Relatively high plane-wave electric field levels were obtained within the GSM 900 and UMTS bands. The field contributions from FM broadcast and VHF TV at this location were the lowest. The highest frequency band electric field strength was estimated at 1.0 m as 269.18 ± 38.76 mVm^{-1} within the UMTS (WCDMA/3G) band with an associated power density of 192.20 ± 27.68 $\mu W/m^2$. The site complied with the recommended ICNIRP reference levels for public exposure for each frequency band. The total exposure quotient for this location was 0.0000357, about 0.0036% of the limit of unity.

Airport Roundabout

Results indicate that there is a consistent variation of electric field strength with antenna orientation with the log periodic antenna elements aligned with the vertical and horizontal planes. The greatest field levels were obtained when antenna elements were aligned with the vertical plane (Y-axis). In Figure 23, the corrected plane-wave electric field strengths obtained at 1.7 m above ground for each frequency investigated were plotted. Field levels were generally very low at this location. The time-averaged electric field strengths for each frequency at the four spatial heights shows that relatively high fields occurred at a spatial height of 2.0 m for all the bands investigated. The highest of 0.957 ± 0.134 Vm^{-1} due to transmissions at 953.1 MHz occurred at UHF band. Figure 24 shows the plotted field levels for each frequency at the four spatial heights.

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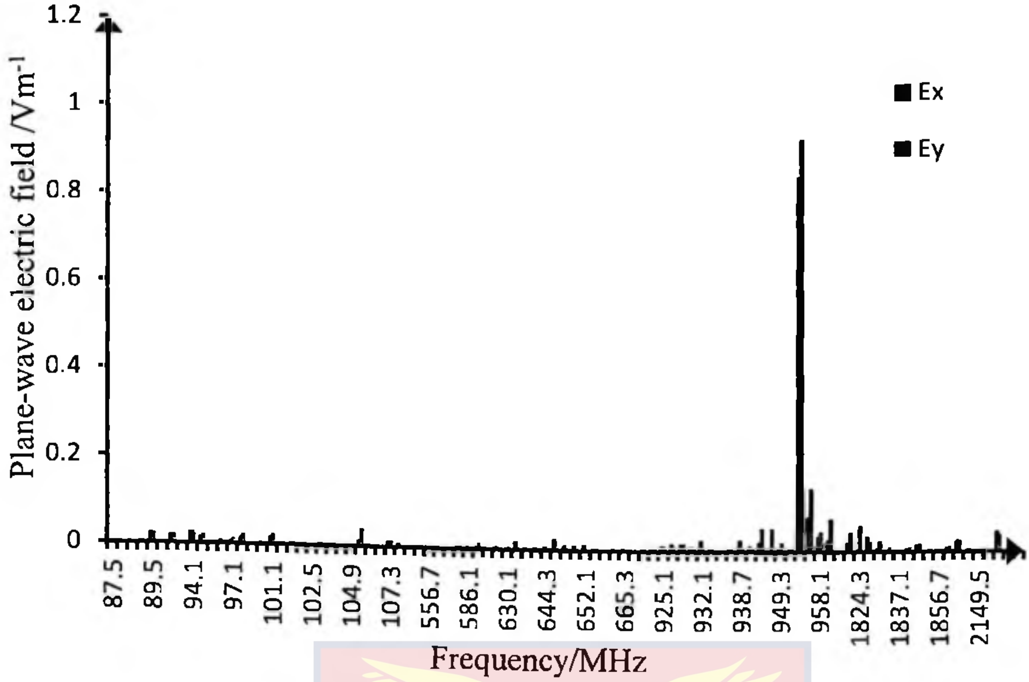

Figure 23: Variation of Electric Field Antenna Elements Orientations at 2.0 m at Airport Roundabout.

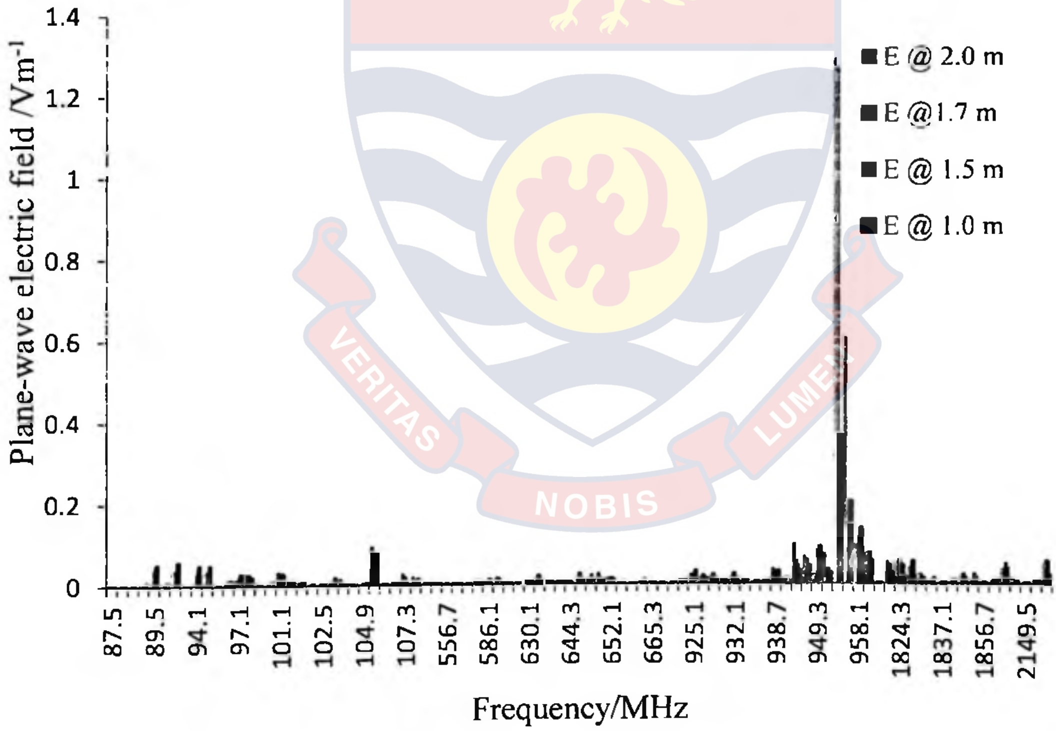

Figure 24: A Plot of Time-averaged E-fields at 1.0 m, 1.5 m, 1.7 m, and 2.0 m at Airport Roundabout

The spatial averaged electric field values for each frequency at this location were plotted in Figure 25. The individual emissions from each frequency were compliant with ICNIRP guidelines. The maximum spatial

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averaged field level was 1.916 ± 0.268 Vm^{-1} at 953.1 MHz with an associated power density of 0.010 ± 0.001 W/m^{-2}. At 955.1 MHz, a second high of 0.6769 ± 0.095 Vm^{-1} was obtained.

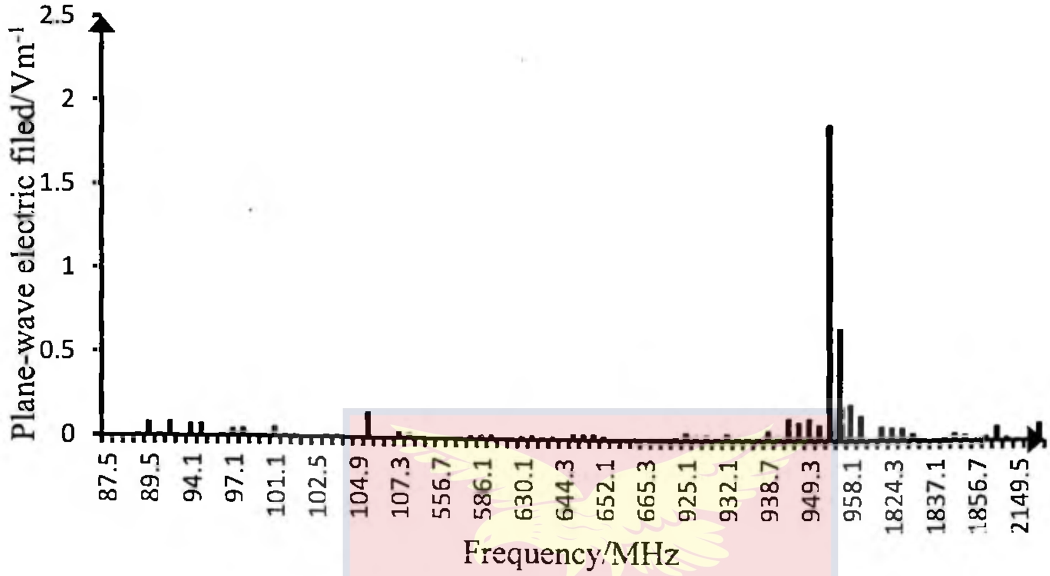

Figure 25: A Plot of E (spatial average) against Frequency for Airport Roundabout.

Table A12 (in Appendix A) shows a summary of the numerical results for Airport Roundabout location per the frequency bands investigated. The maximum spatial averaged plane-wave electric field strength came from UMTS (WCDMA/3G) band with a numerical value of 216.47 ± 30.96 mVm^{-1}. The highest field levels within the FM and UMTS (WCDMA/3G) bands were recorded at 1.0 m above ground.

Adum

Results from measurement analysis revealed that electric field levels do vary with antenna element orientation within the field being detected. With antenna aligned with the vertical plane, the highest field strength levels were detected (Figure 26). The maximum field level measured at this location was 0.4909 ± 0.0691 Vm^{-1} at a height of 1.7 m above the ground. Relatively very

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high field levels were obtained from FM radio transmissions than from other sources.

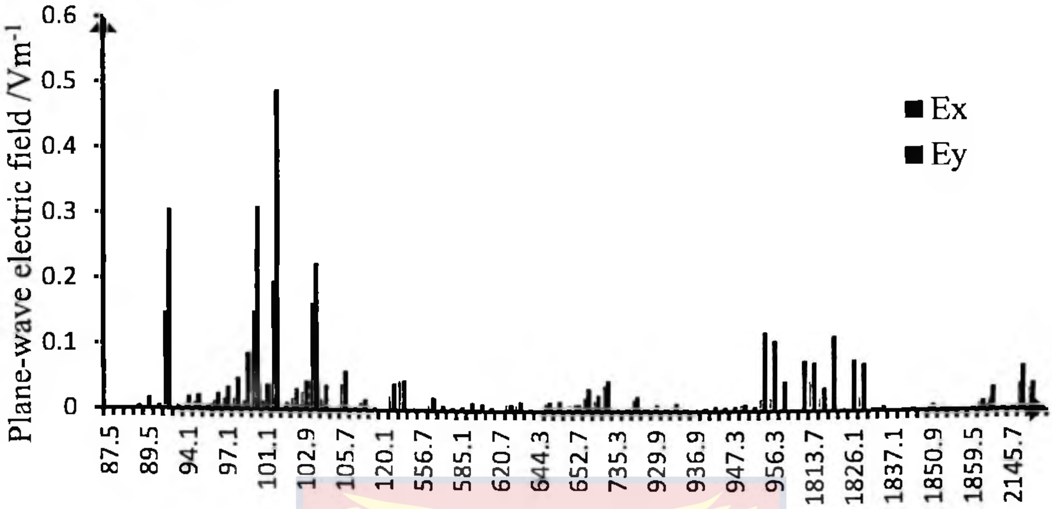

Figure 26: Variation of Electric Field Antenna Elements Orientations at 1.7 m at Adum.

The time-averaged electric field strengths for each spatial height did not show a clear sequence of variation of electric field with height. In Figure 27, a plot was made of the time-averaged plane-wave electric field strengths at the four spatial heights.

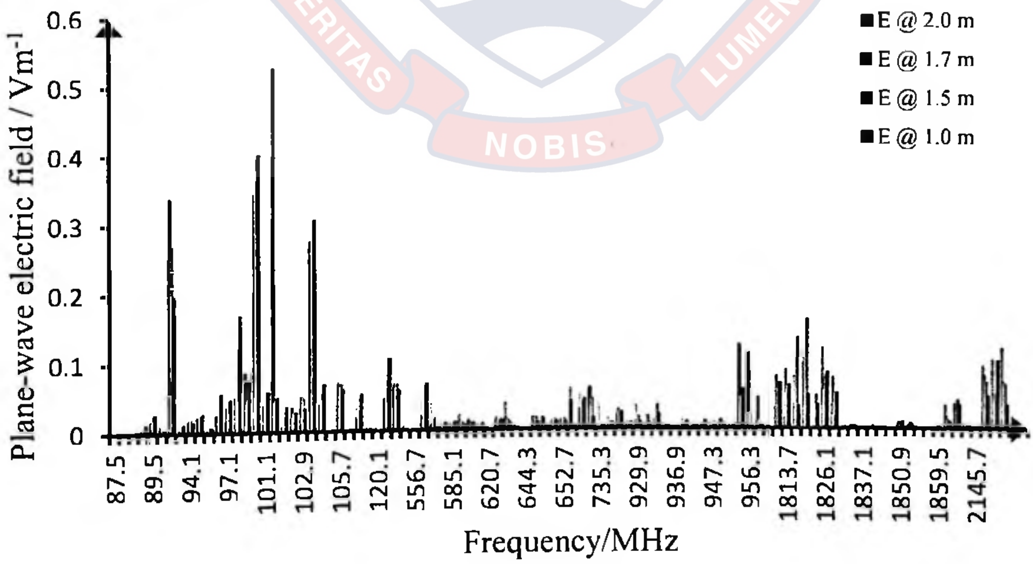

Figure 27: A Plot of Time-averaged E-fields at 1.0 m, 1.5 m, 1.7 m, and 2.0 m at Adum.

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The maximum time-averaged field level per height was determined at to be 0.5288 ± 0.0748 Vm^{-1} at a spatial height of 1.7 m. This occurred at 101.5 MHz. Field levels of similar magnitudes occurred from transmissions at three other FM frequencies. The spatial averaged plane-wave electric field strength

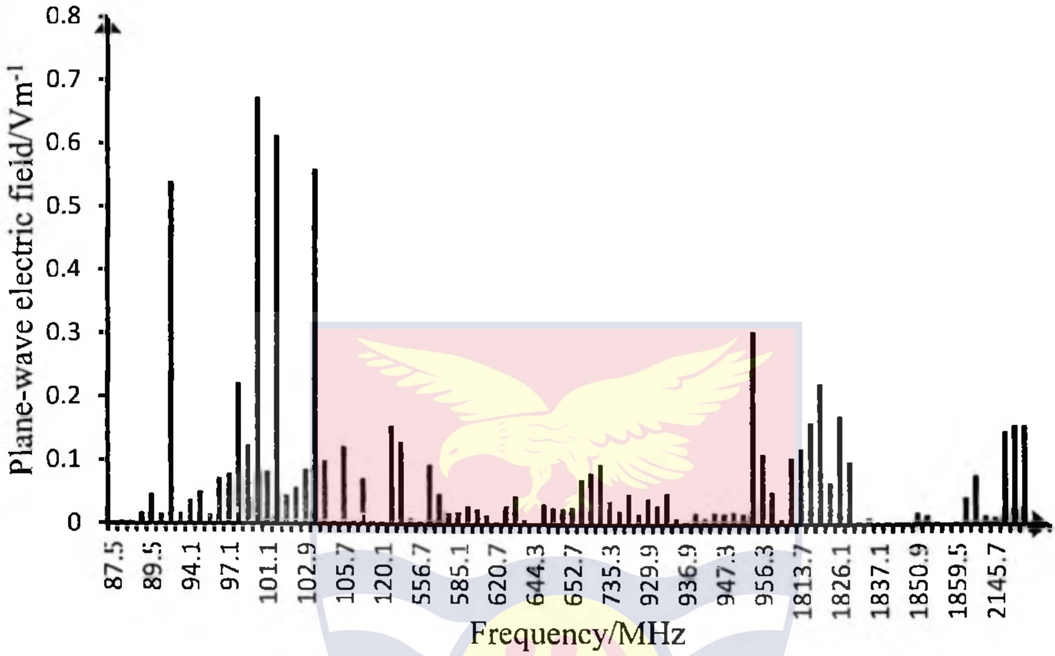

Figure 28: A Plot of Electric Field (spatial average) against Frequency for Adum.

values for each frequency were plotted in Figure 28. The maximum field level for Adum was 0.6757 ± 0.0956 Vm^{-1} at 99.5 MHz followed closely by 101.5 MHz at 0.6157 ± 0.0871 Vm^{-1}. This location therefore complies with the ICNIRP benchmarks for public exposure. In all, 96 RF sources were detected at the time of carrying out this study.

The detailed numerical results for measurement at this location are outlined in Table A13 (in Appendix A). Very high field strengths contributions came from within the FM broadcast band. A maximum of 785.73 ± 111.18 mVm^{-1} was determined at 1.7 m above ground followed with 599.33 ± 84.81 mVm^{-1} within the same band. Contributions from VHF TV

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(174 -230 MHz) are the lowest. Over all, field contributions from all the frequency bands investigated at this location are significantly high. This might be as a result of the undulating nature of the location and the elevation of the measurement point. This location is a commercial hub and the demand for quality of service might be high. The location however is compliant with the ICNIRP recommended levels for public exposure. The total exposure quotient for the location was 0.0000443 representing 0.004% of ICNIRP recommended levels of unity.

Manhyia

Results from measurements at this location revealed that the field levels are highest at a height of 1 m from the floor in almost all the measurements. The highest corrected plane-wave electric field of 0.8600 ± 0.12126 V/m was obtained at 1 m when the antenna elements were oriented in the Y-axis. An FM radio transmitting at 101.9 MHz generated this maximum field. Results here indicate a trend of higher values when stacked antenna elements are aligned with the Y-axis than those obtained with an alignment with X-axis. Similar trend was observed for field levels from two other FM radio transmissions; 102.9 MHz and 94.1 MHz. The highest resolved field level at the four heights was 0.9276 ± 0.1308 V/m recorded at a spatial height of 2.0 m and occurred at 101.9 MHz and is displayed in Figure 29. The associated power density was 0.00228 ± 0.00032 Wm^{-2}. After spatially averaging the resolved electric field values at the four spatial heights, the location Manhyia, recorded a range of values of electric field spanning 0.00284 ± 0.0004 V/m to 1.85356 ± 0.26135 V/m.

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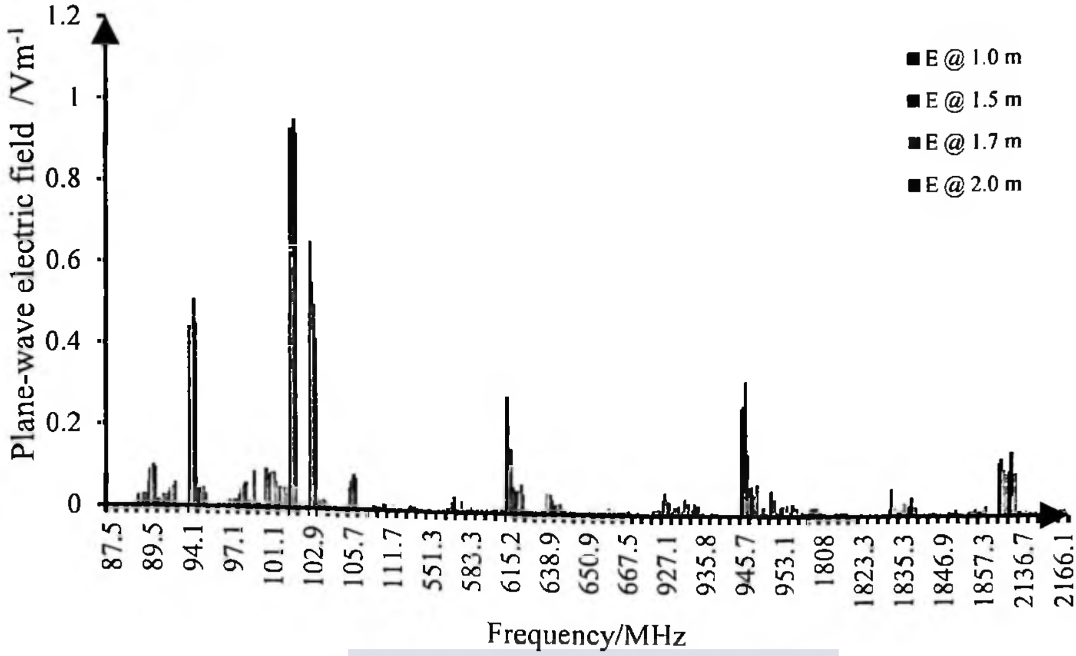

Figure 29: A Plot of Time-averaged E-fields at 1.0 m, 1.5 m, 1.7 m, and 2.0 m at Manhyia

These field levels are well below the ICNIRP benchmark. In Figure 30, the spatially averaged field levels fare plotted for each frequency of interest. Contributions from FM sources dominated the field levels here. The electric

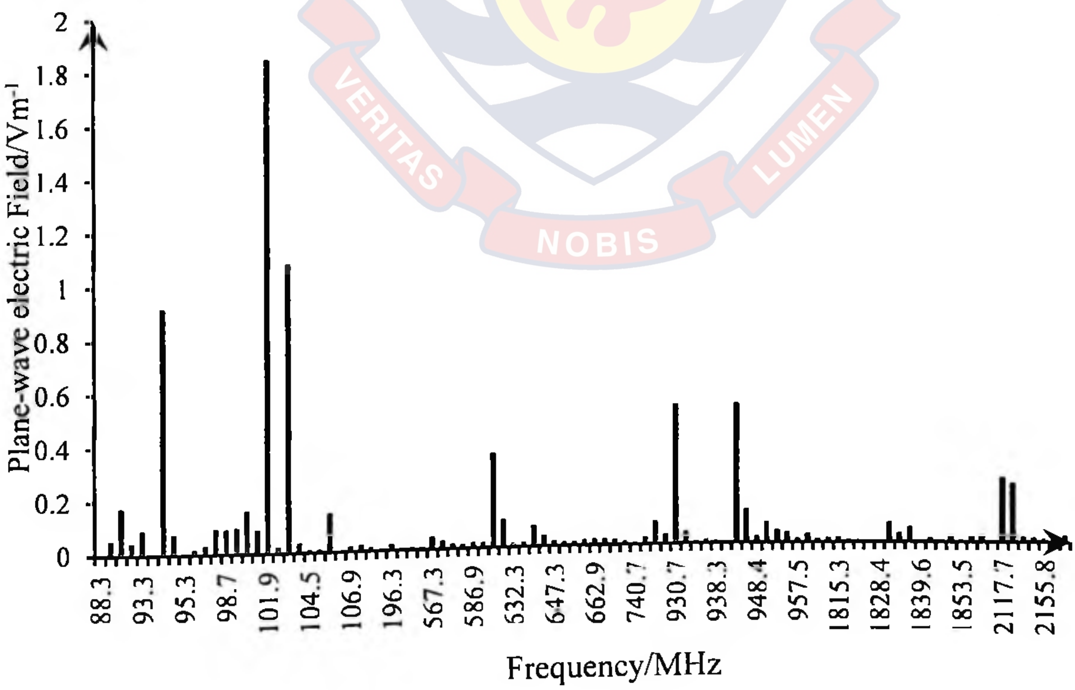

Figure 30: A Plot of Electric Field (spatial average) against Frequency for Manhyia.

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field levels due to individual sources (frequencies) did complied with ICNIRP limits. The exposure quotient for the highest field per frequency was 0.03312 ± 0.0046 representing 3.3% of the ICNIRP recommended limit of unity. The highest power density at this location due to RF sources detectable is 0.0091 Wm^{-2}. This location therefore complies with the ICNIRP benchmarks. In all, 96 RF sources were detected at the time of carrying out this study. The total exposure quotient for the location was 0.0000443.

In Table A14 (in appendix A), a summary of the numerical findings within the six bands at this location was presented. Relatively very high values were observed for FM broadcast band. Contributions from within the VHF TV band are the least. Maximum field levels were detected at 1.0 m above ground within FM broadcast, UHF TV and UMTS (WCDMA/3G) bands. The total exposure quotient for the site was 4.43E-05 ± 6.25E-06 representing 0.004% of the recommended limit of unity. The site is ICNIRP compliant.

UEW College of Technology

Results indicated that the highest field levels occurred when the antenna elements were rotated to align with the vertical plane. At a height of 1.0 m above the floor, relatively high electric field values were obtained within 945.7 MHz – 950.3 MHz band (Figure 31). Figure 32 shows a plot of time-averaged plane-wave E-fields for the spatial heights 2.0 m, 1.7 m, 1.5 m, and 1.0 m against the various frequency bands investigated. The highest E-field value of 0.0946 ± 0.0133 V/m was obtained at 1.7 m for frequency of 2117.7 MHz.

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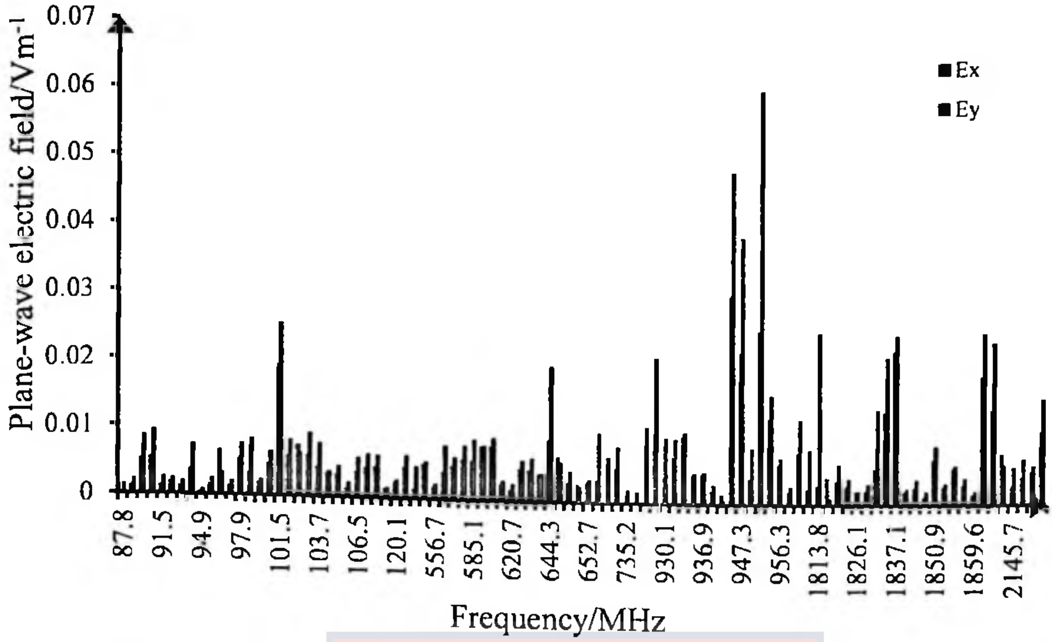

Figure 31: Variation Of Electric Field with Antenna Element Orientations at 1.0 m at UEW College of Technology

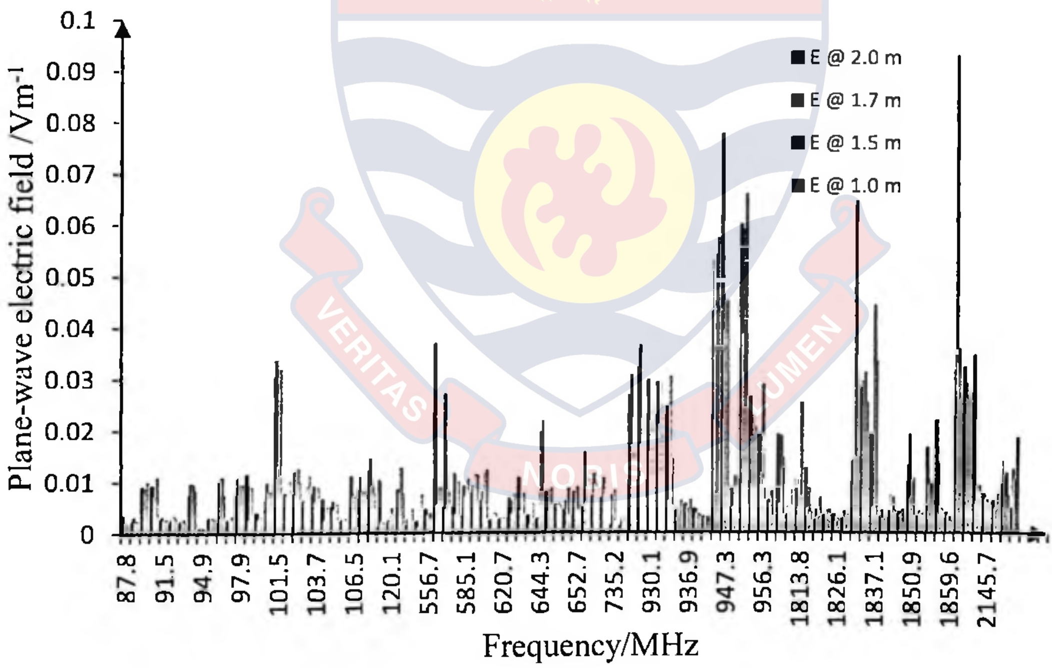

Figure 32: A Plot of Time-averaged E-fields at 1.0 m, 1.5 m, 1.7 m, and 2.0 m at UEW College of Technology

This is an isolated case as different frequencies recorded the maximum field strengths at other heights. Sources radiating within the UHF band produced the highest fields at this location. A plot of the spatially averaged field levels against frequency in Figure 33 for this location shows that the

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highest field for this location was 0.11586 ± 0.01633 Vm^{-1} at 950.3 MHz with an associated power density of 3.56E-05 Wm^{-2}. Electric field strength from UHF band dominated the contributions here. A total of 96 RF sources contributed to the field level at this location.

Table A15 (in Appendix A) shows a summary of the numerical results of the analysis of data at this site. UMTS (WCDMA/3G) band contributed the highest proportion of the spatial averaged fields. The least field contributions came from VHF TV band. The total exposure quotient at this location was 1.98E-05 ± 2.84E-06 representing 0.002% of the recommended limit of unity. The site is ICNIRP compliant.

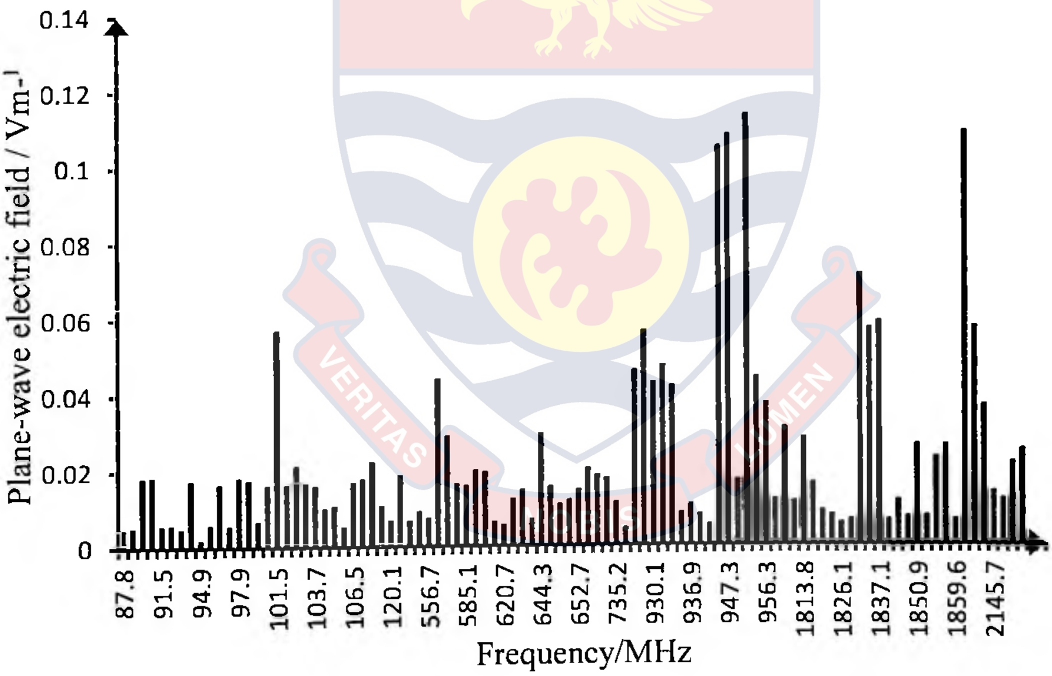

Figure 33: A Plot of E (spatial average) against Frequency for UEW College of Technology

Prempeh College

The results indicate that the field strength at this location varied significantly with height and antenna element orientation. The electric field strength contributions came from 95 sources. The highest instantaneous plane–

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wave electric field strength of 0.1 ± 0.014 Vm^{-1} was determined at 953.1 MHz. In Figure 34 the variations of the fields with antenna orientations were plotted.

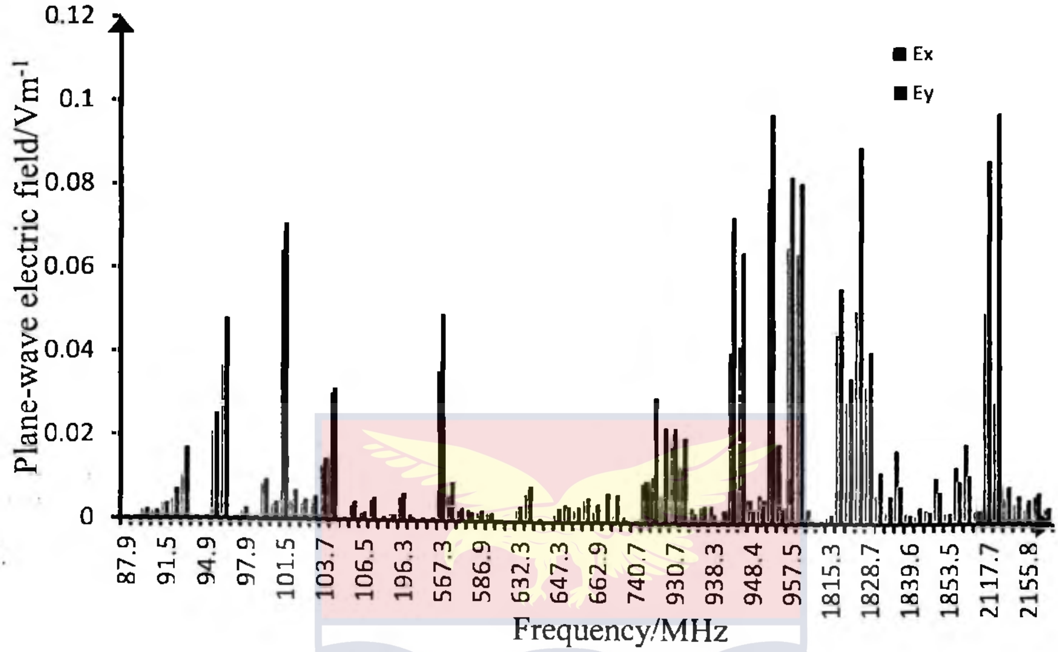

Figure 34: Variation of Electric Field with Antenna Elements Orientations at 2.0 m at Prempeh College

At this location, the field strengths detected with antenna elements aligned with the vertical plane (Ey) are relatively higher than field levels detected with the elements aligned with the horizontal plane. UHF produced the maximum field strengths at this location. In a plot of the time-averaged plane-wave electric field strength against frequency in Figure 35, relatively high values occurred at a spatial height of 1.5 m above ground. These values span across the entire spectrum investigated. The maximum field strength of 1.5723 ± 0.2251 Vm^{-1} was the result at 222.3 MHz. Here again the frequencies yielding these maximum field values are more at the UHF band. Relatively high contributions were detected at spatial heights of 1.0 m and 1.5 m.

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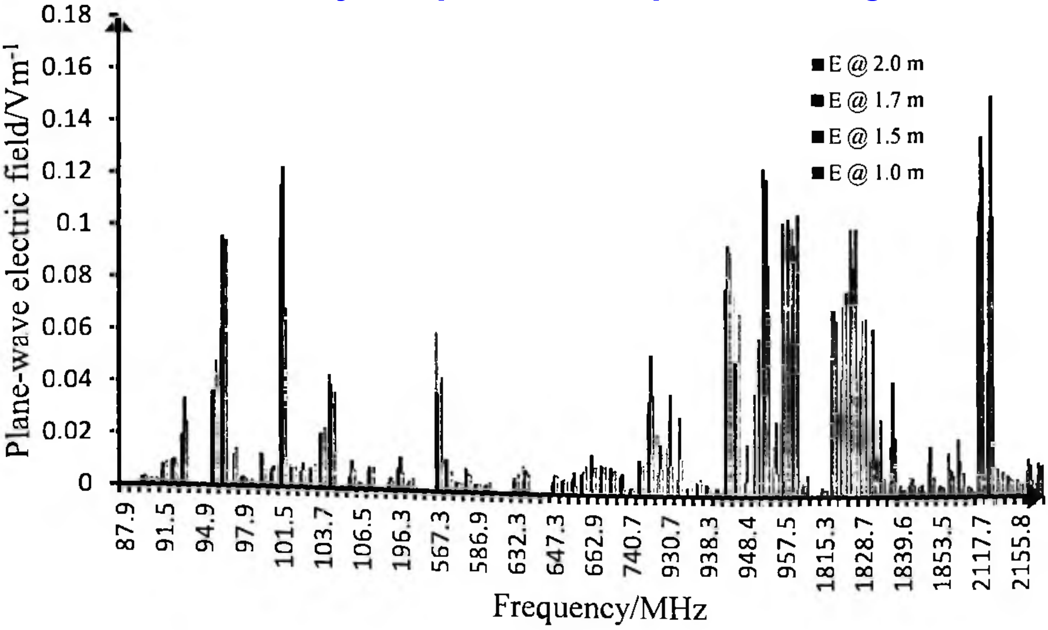

Figure 35: A Plot of Time-averaged E-fields at 1.0 m, 1.5 m, 1.7 m, and 2.0 m at Prempeh College.

In Figure 36, the plane-wave electric fields at the four spatial heights were spatially averaged to obtain a single electric field value for each frequency investigated. The maximum field per frequency evaluated for this location was 0.2235 ± 0.0321 Vm^{-1} at 2122.3 MHz with an associated power density of 0.13 ± 0.01 mWm^{-2}.

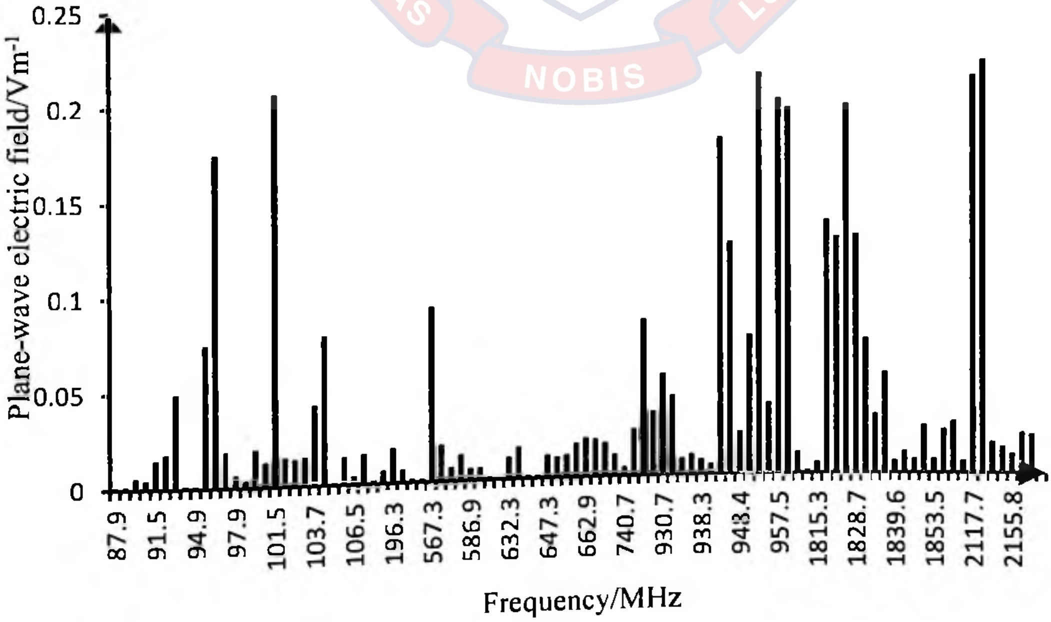

Figure 36: A Plot of E (spatial average) against Frequency for Prempeh College.

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Table A16 (in Appendix A) displays the summary of the numerical results for the location for the bands (grouped frequencies) investigated. GSM 900 band contributed the highest field level at this located. Contributions from FM broadcast and UMTS (WCDMA/3G) bands are significantly high. The total exposure quotient for this location was 7.83E-05 ± 1.12E-05 representing 0.008% of the ICNIRP limit. The highest power density calculated for this location was 0.0065573 ± 0.00094 Wm^{-1} out of a compliant level of unity.

Electric Field Trend at Accra-Tema Sites

Airport-Aviance

Results at this location show relatively high field levels occurring randomly per orientation of stacked antenna elements in the vertical and horizontal planes. The values of the corrected plane-wave electric field range from a high of 0.32199 ± 0.0455 Vm^{-1} through to field levels as low as 9.955E-05 ± 1.41E-05 Vm^{-1}. Resolved field strength at each spatial height puts the highest field level at 0.45234 ± 0.0641 Vm^{-1} at a spatial height of 2.0 m. Other frequencies recorded relatively high field levels at varying heights and the details are as displayed in Figure 37. The location has very low field contributions from FM radio transmissions as well as from VHF TV and UHF TV transmissions. The higher field levels were concentrated at frequencies above 900 MHz. These frequencies are used for mobile telephony. The spatially averaged electric field strength for each frequency investigated is plotted in Figure 38. The highest field level at this located was 0.58123 ± 0.0822 Vm^{-1} and it occurred at 946.3 MHz. Electric field strength from UHF were predominant at this site.

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The maximum power density at this site was 0.00089 ± 0.00013 W/m^2.

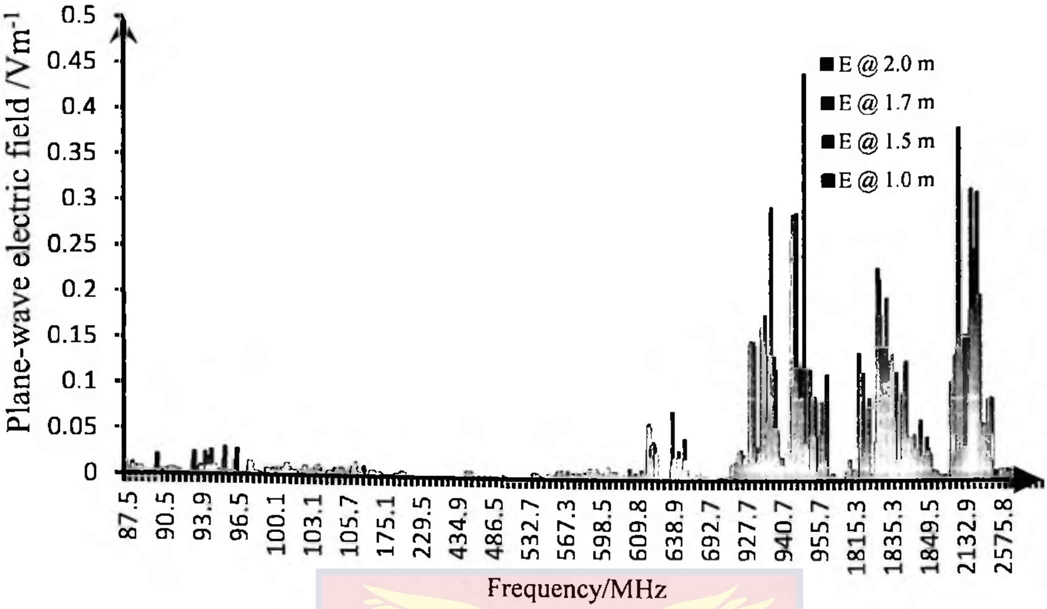

Figure 37: A Plot of Time-averaged E-fields at 1.0 m. 1.5 m. 1.7 m. and 2.0 m at Airport-Aviance

In Table A17 (in appendix A), the numerical results for this site were summarized. GSM 900 band contributed the highest fields at this location. There was no clear pattern of variation of plane-wave electric field with spatial height.

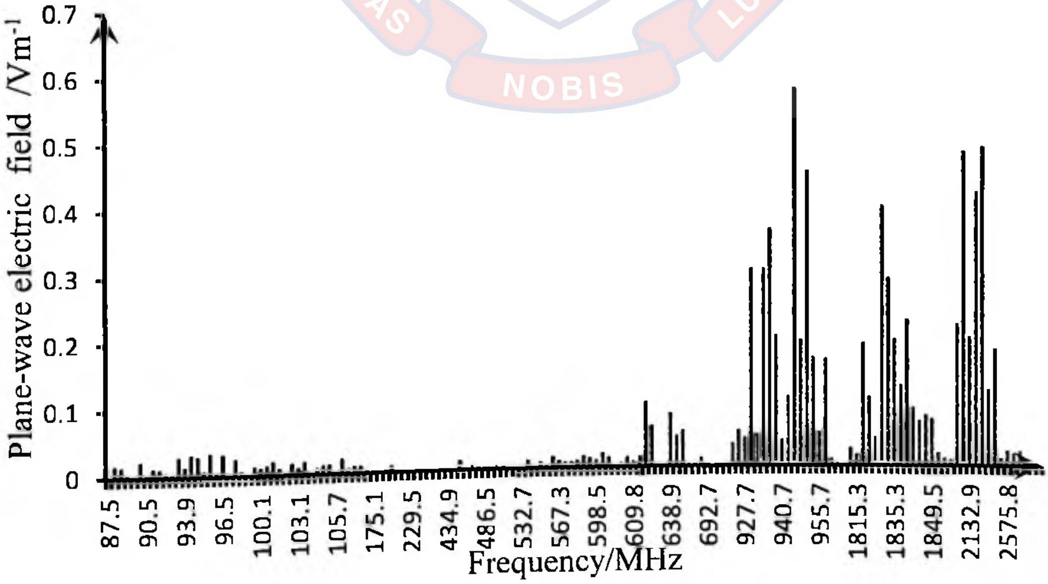

Figure 38: A Plot of E (spatial average) against Frequency for Airport-Aviance

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Very low field levels were produced by sources within the VHF TV band. The Total exposure quotient for this location was 2.10E-04 ± 2.97E-05 representing 0.02% of the ICNIRP recommended limit of unity. A total of 147 RF sources contributed to the field level at this location. This site was ICNIRP compliant.

Rawlings Park

Analysis of measurements from this location shows that very low field strength is present at frequencies below 800 MHz. The higher field levels at this location were due to sources operating at UHF. There was no clear pattern of variation in field levels with spatial height. Relatively high field levels occurred randomly at different spatial heights. The detailed plot of the variation of field strength with frequency for the time-averaged plane-wave electric field strengths is shown in Figure 39.

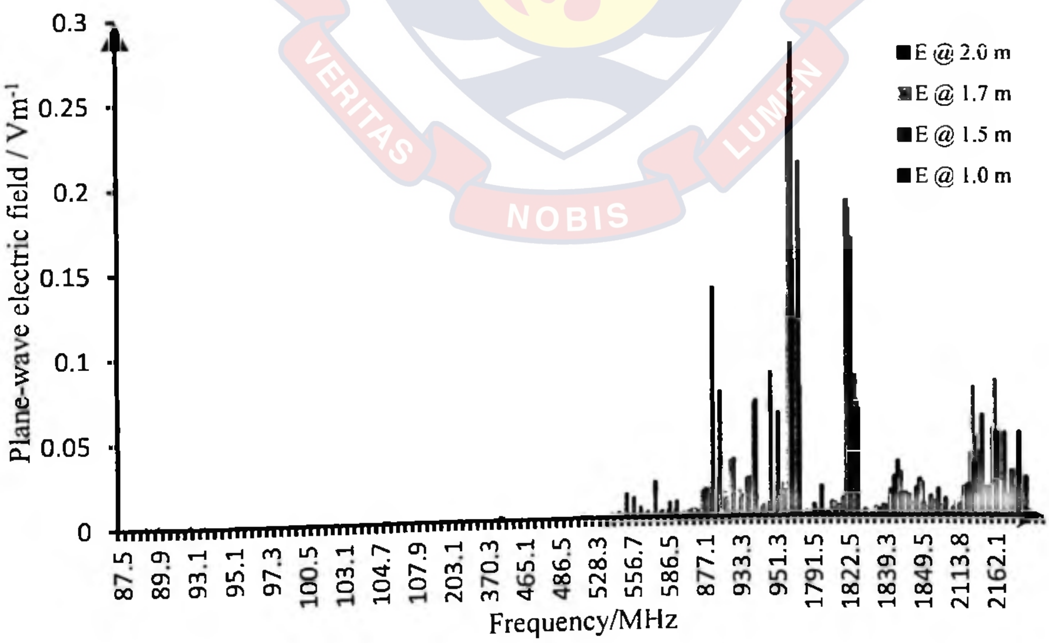

Figure 39: A Plot of Time-averaged E-fields at 1.0 m, 1.5 m, 1.7 m, and 2.0 m at Rawlings Park

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The highest electric field of 0.28543 ± 0.0404 Vm^{-1} was detected at 955.7 MHz at a spatial height of 1.5 m above ground. A plot of the spatially averaged field levels against frequency in Figure 40 shows that the highest field for this location was 0.48694 ± 0.0689 Vm^{-1} with an associated power density of 0.628 ± 0.089 mWm^{-2}. A total of 125 RF sources contributed to the field level at this location. Each of the electric fields due to a particular frequency is compliant with ICNIRP recommended level.

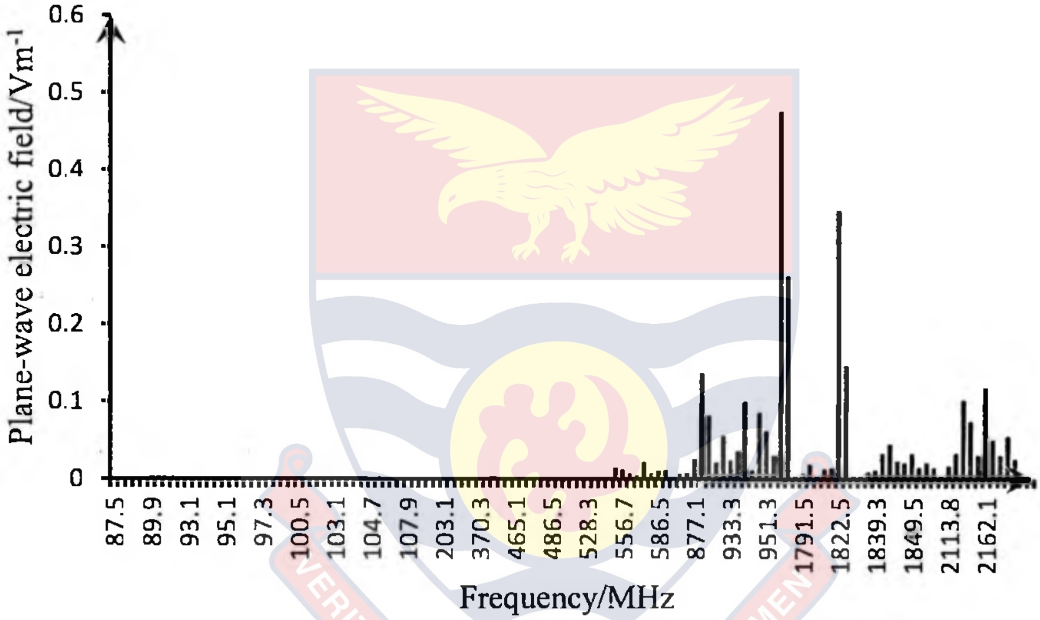

Figure 40: A Plot of E (spatial average) against Frequency for Rawlings Park.

A summary of the numerical results from analysis of data obtained at this location is displayed in Table A18 (in appendix A). The lowest spatial average field strength came from sources transmitting at VHF TV band. The minimum electric field strength at this location was 0.49 ± 0.07 Vm^{-1} at a height of 2.0 m above ground. The maximum field strength was calculated at 1.5 m above ground within the GSM 900 band. The value was 367.18 ± 52.29 mVm^{-1} with an associated power density of 357.616 ± 50.9245 $\mu W/m^2$. The total exposure quotient for this location was estimated at 2.22E-04 ± 3.16E-05

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representing 0.02% of the recommended ICNIRP limit of unity. The site complied with ICNIRP levels.

Korle-Bu Teaching Hospital

Results indicate that electric field distribution at the point of interest varied with both height and antenna orientation. Relatively high values were obtained for antenna orientations that aligned the antenna's log periodic elements with the vertical plane (Y-axis) in more than 95% of the instances. The highest corrected electric field strength obtained at the hospital's premises due to FM radio broadcast was 0.0162 ± 0.002 Vm^{-1} at a spatial height of 1.7 m above ground level with the antenna elements aligned with the vertical plane. This field strength has an associated power density of 6.97E-07 ± 1.00E-07 Wm^{-2}. The highest electric field for this location was 0.3648 ± 0.019 Vm^{-1} giving rise to the highest power density of 0.35 ± 0.05 mWm^{-2}. Figure 41 shows a plot of the variation of the field levels at a spatial height of 1.7 m.

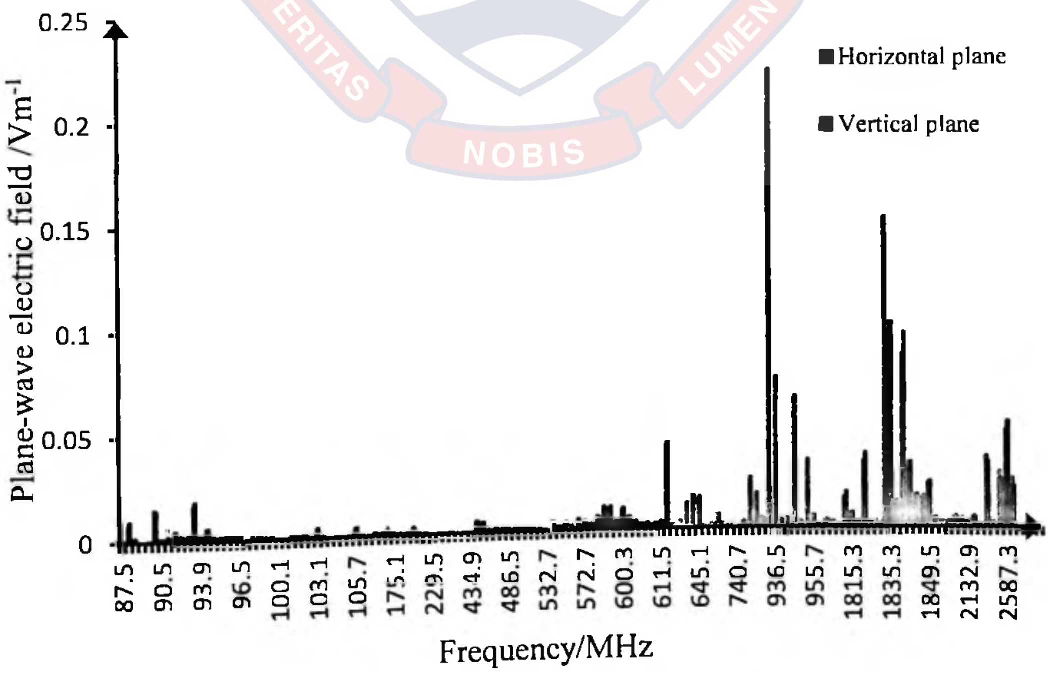

Figure 41: Plot of Electric Field against Frequency for Antenna Orientation at 1.7 m for Korle-Bu Teaching Hospital

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The time-averaged plane-wave electric field strength for this location as plotted in Figure 42 revealed the maximum measured field strength to be 0.3038 ± 0.0425 Vm^{-1} at 933.3 MHz. This occurred at 1.5 m above ground.

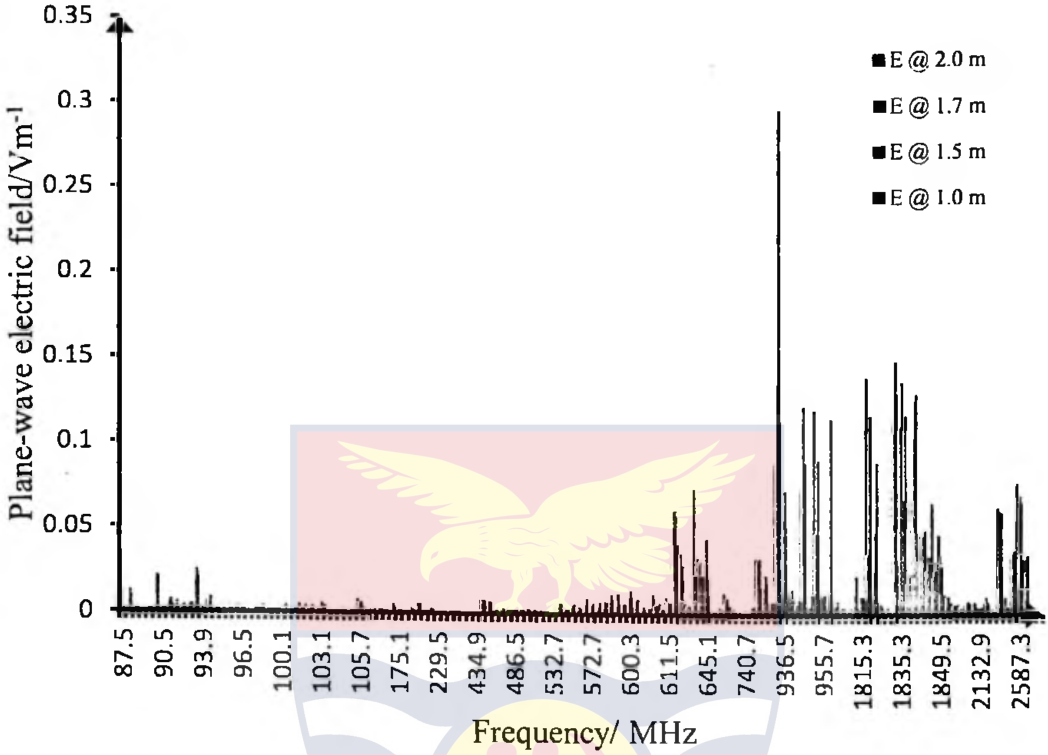

Figure 42: A Plot of Time-averaged E-fields at 1.0 m, 1.5 m, 1.7 m, and 2.0 m at Korle-Bu Teaching Hospital

The time-averaged electric field values at the four spatial heights at the Korle-Bu Teaching Hospital location recorded range of 0.25 ± 0.035 mV/m to 0.36413 ± 0.05101 V/m. The maximum fields occurred at UHF band. Figure 43 show the plot of the distribution of the spatially averaged plane-wave fields over the frequency range of 87.5 MHz to 2.6 GHz at this location. The highest power density due to the strongest field at this location is 0.353 ± 0.049 mW/m^2. In Table A19 (in Appendix A), summary of numerical results were presented for the six frequency bands investigated.

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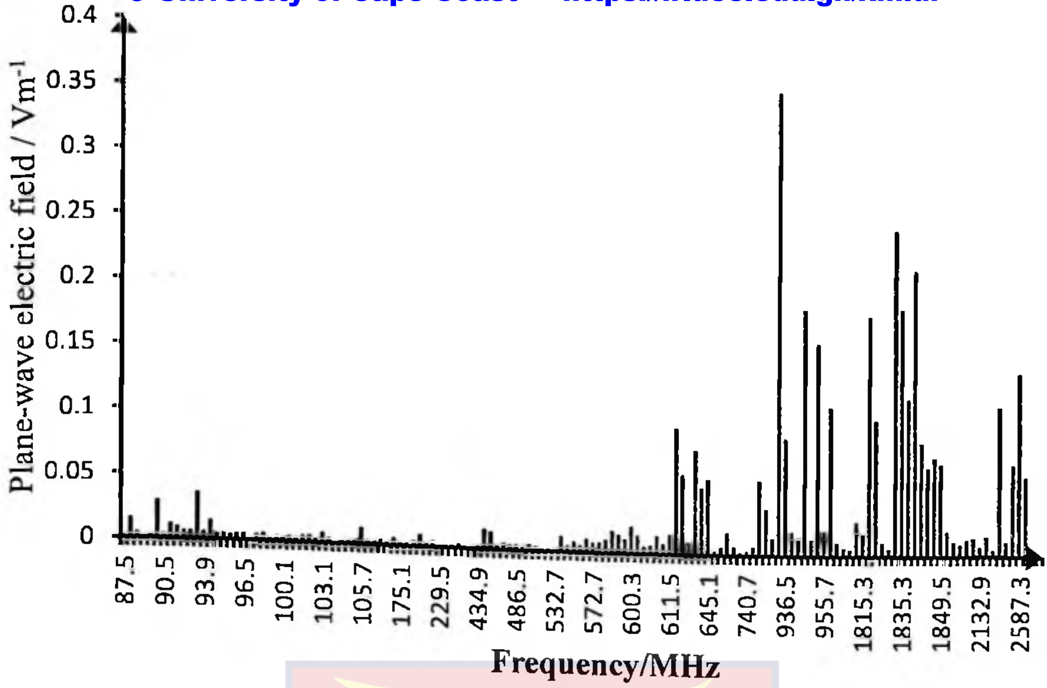

Figure 43: A Plot of E (spatial average) against Frequency for Korle-Bu Teaching Hospital

FM broadcast band produced the lowest level of fields whilst GSM 900 band contributed the most field strength. The Total exposure quotient for this location was 4.24E-06 ± 5.94E-07. The location is ICNIRP compliant.

Tema Roundabout

Results indicated that the plane-wave electric field strength varies with antenna element orientation. Relatively high values were obtained for antenna orientations that aligned antenna elements in the vertical plane (Ey) in most instances. Such variations are plotted in Figure 44. Predominantly, sources transmitting within the UHF band contributed the highest electric fields at this location. The maximum field strength was determined to be 0.2061 ± 0.0291 Vm^{-1} at 933.3 MHz. The time-averaged electric field strengths as plotted in Figure 45 revealed that the maximum field strength for this location was 0.3038 ± 0.0429 Vm^{-1} at a spatial height of 1.5 m.

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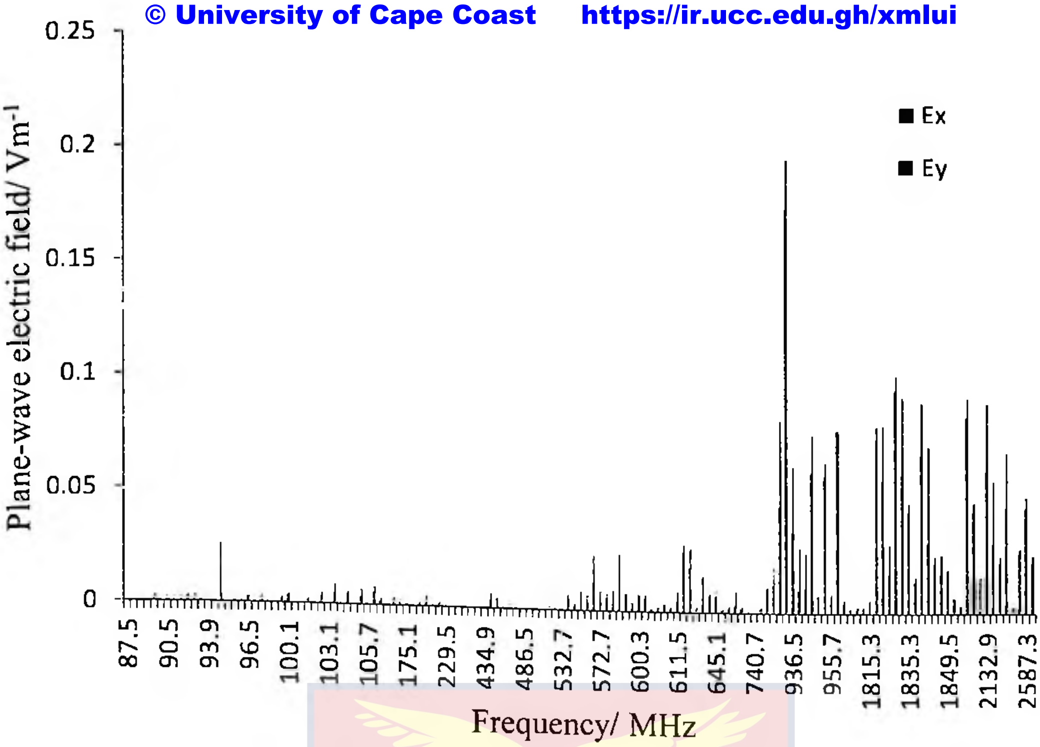

Figure 44: Variation of Electric Field Antenna Elements with Orientations at 1.0 m at Tema Roundabout location

This height recorded other high electric field strengths within the UHF band. Contributions from FM radio transmissions are comparatively very low.

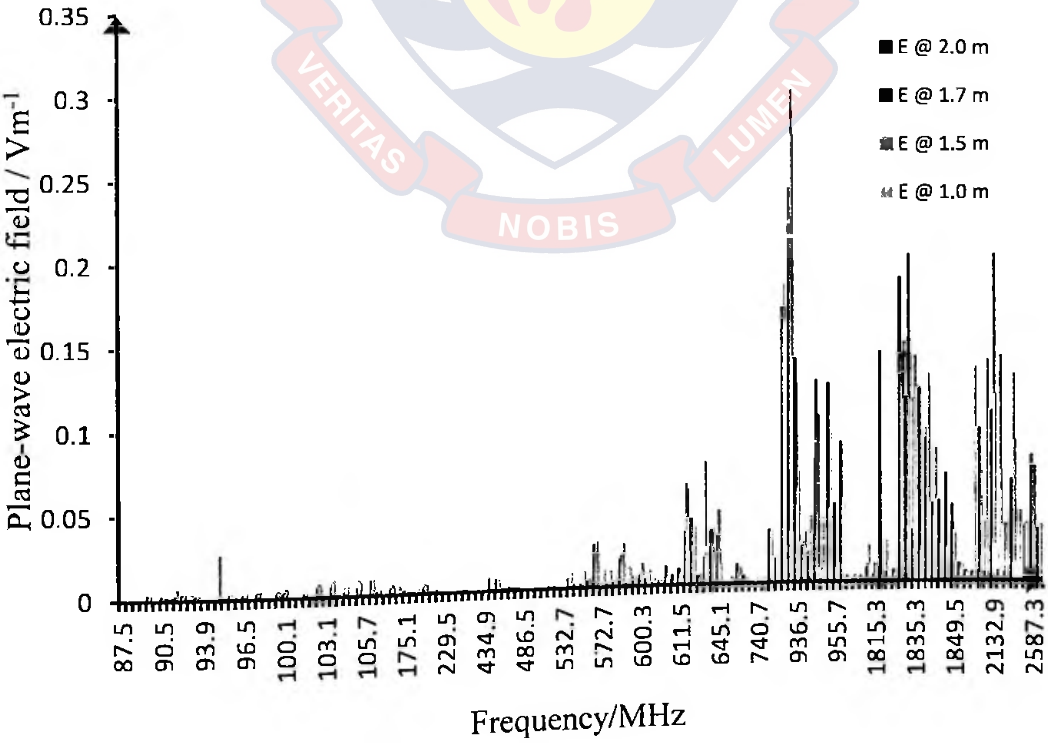

Figure 45: A Plot of Time-averaged E-fields at 1.0 m, 1.5 m, 1.7 m, and 2.0 m at Tema Roundabout

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The spatial-averaged plane-wave electric field strength of the four spatial heights ranged of 0.3873 ± 0.0547 V/m to 0.52797 ± 0.0745 V/m. Figure 46 shows the plot of the distribution of the spatially averaged fields over the frequency range of 87.5 MHz to 2.6 GHz. The highest power density due to the strongest field at this location is 739.11 ± 0.0104 μW/m^2.

Table A20 (in Appendix A) shows a summary of numerical results for each of the six bands at this location. The spatial average plane-wave electric field contributions from GSM 900 band are the highest at this location. The maximum value of the spatial average plane-wave electric field strength was 384.02 ± 54.91 mV/m with an associated power density of 391.17 ± 55.94 μW/m^2. The least contributions came from within the VHF TV band. The total exposure quotient for the site was 0.00126 ± 0.000178 representing about 0.12% of the recommended ICNIRP limit of unity. This location therefore

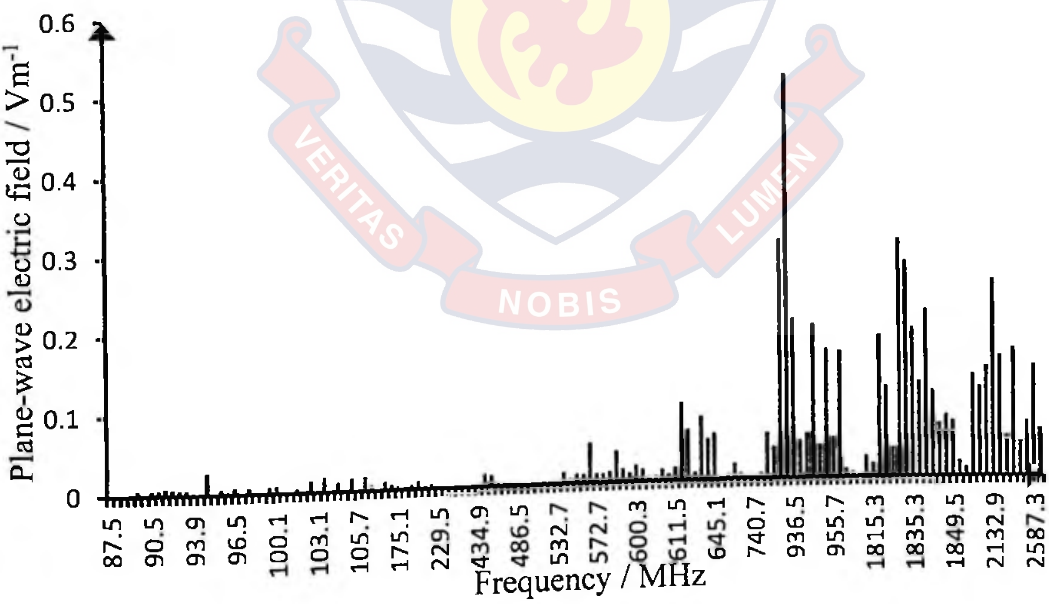

Figure 46: A Plot of E (spatial average) against Frequency for Tema Roundabout

complies with the ICNIRP benchmarks. In all, 136 RF sources were detected at the time of carrying out this study.

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Tema Community One

The results here did exhibit a significantly variation of electric field with height and antenna element orientations. Variations of electric field strength with spatial height occurred randomly at varying frequencies. However, relatively high contributions were detected when the log-periodic antenna elements were aligned with the vertical plane (Figure 47). The maximum field strength at 1.0 m above ground was 0.4954 ± 0.0708 Vm^{-1}. The electric field strengths contributions here came from 140 sources. The predominantly high field levels were due to transmissions in the UHF bands.

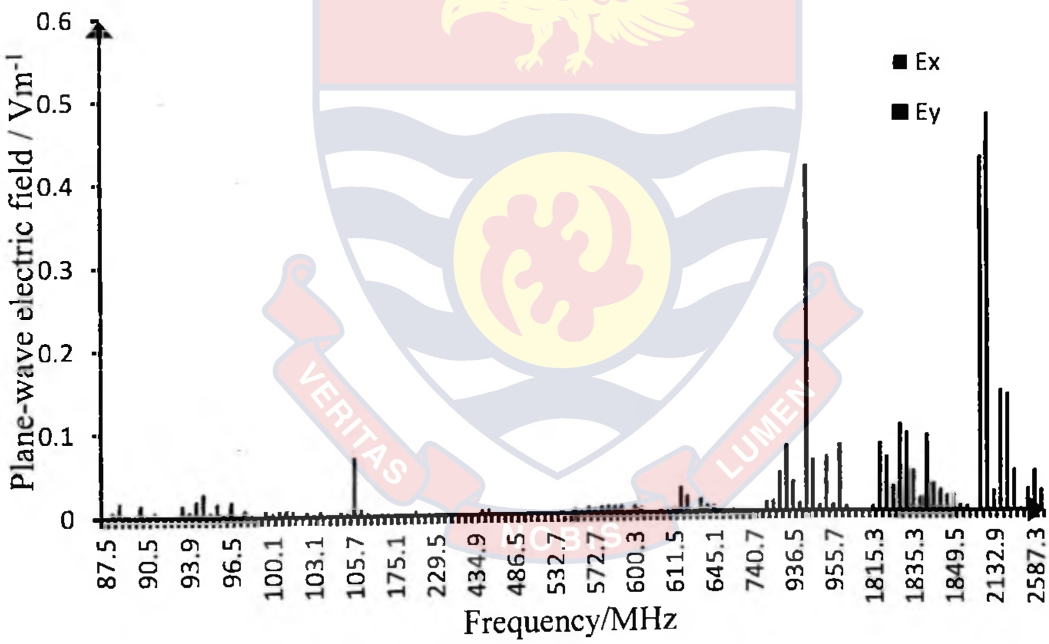

Figure 47: Variation of Electric Field Antenna Elements with Orientations at 1.0 m at Tema Community One

The Time-averaged electric field strengths at the four spatial heights were plotted in Figure 48. The maximum time-averaged electric field strength occurred at a height of 1.0 m with a value of 0.67588 ± 0.0967 Vm^{-1}. This value occurred at 2121.5 MHz. The difference between the highest field

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strength and the lowest was 0.6235 ± 0.0892 Vm^{-1}. The spatial-averaged

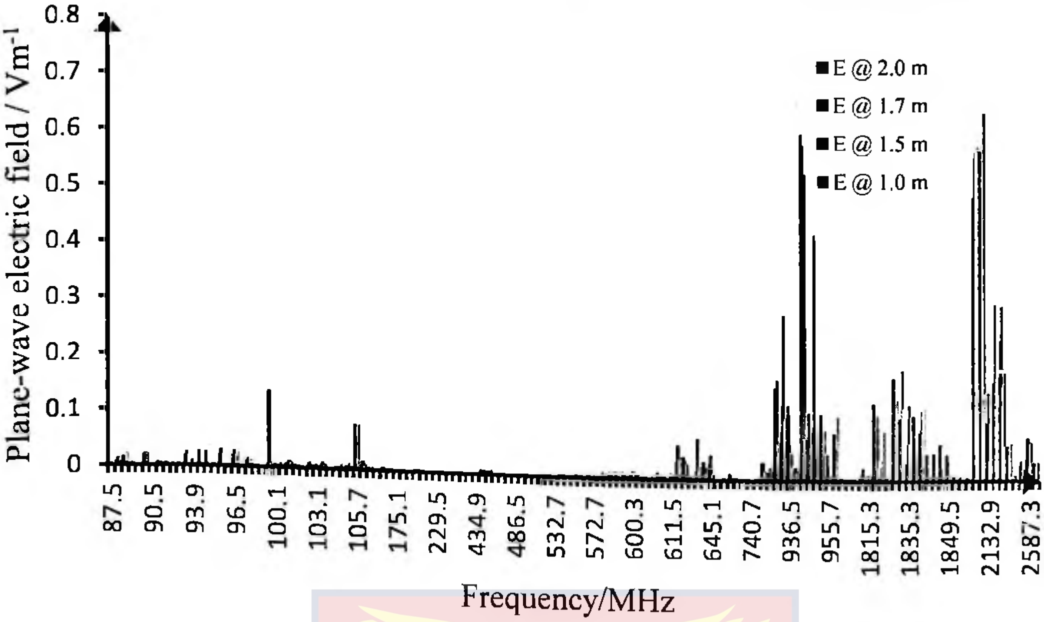

Figure 48: A Plot of Time-averaged E-fields at 1.0 m, 1.5 m, 1.7 m, and 2.0 m at Tema Community One

electric field levels for the four spatial heights were plotted against frequency in Figure 49. The highest field per frequency to which someone is likely to be exposed to at this location was determined to be 1.1659 ± 0.1667 Vm^{-1} with an associated power density at a frequency of 2113.9 MHz.

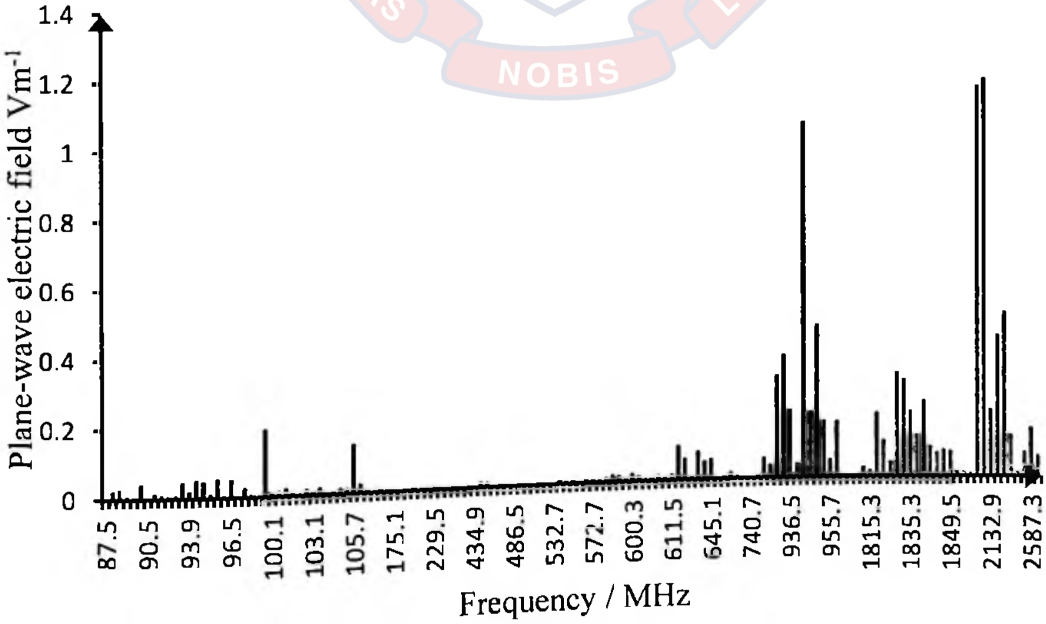

Figure 49: A Plot of E (spatial average) against Frequency for Tema Community One

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Table A21 (in Appendix A) displays the summary of the numerical results for the frequency bands at this location. Contributions from VHF TV band is very low compared with field strengths from the other bands. The electric fields from the bands ranged from 5.08 ± 0.73 mV/m at 1.5 m within the VHF TV band through to 906.12 ± 129.58 mV/m at 1.7 m above ground within the UMTS (WCDMA/3G) band. The power density associated with the maximum electric field at this location was 2177.861 ± 311.43 μW/m². The total exposure quotient at this location was 4.69E-04 ± 6.72E-05. Exposure of members of the public at this location is compliant with ICNIRP recommended levels.

University of Ghana

Analysis of measurement results at this location show a variation of field levels with antenna element orientation as well as with height of antenna from ground level. Levels when stacked antenna elements were aligned in the same plane as the vertical axis are much elevated than when aligned with the horizontal plane. The highest corrected electric field level due to FM radio transmission was recorded at a spatial height of 1.0 m. However UHF contributed higher levels than the FM field level. The highest time-averaged electric field level was 0.64941 ± 0.09313 Vm^{-1} was determined at 1.0 m above ground level. Relatively high field levels occurred at frequencies above 740 MHz and at varying heights. To obtain single field strength for the location at each detected frequency, the levels obtained at the four spatial heights were resolved. The resolved spatial field levels are plotted as a function of frequency in Figure 50.

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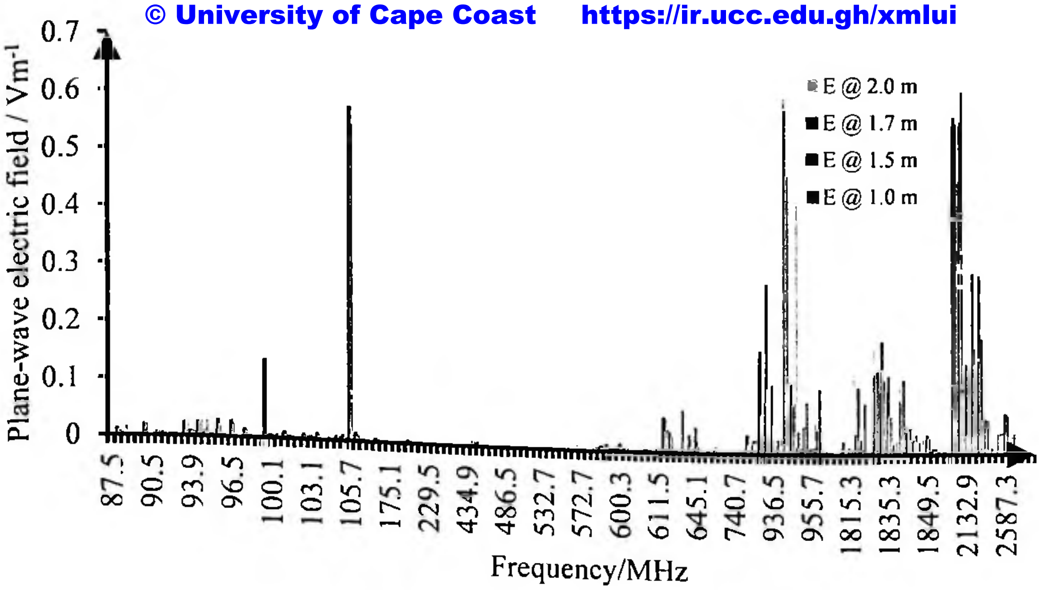

Figure 50: A Plot of Time-averaged E-fields at 1.0 m, 1.5 m, 1.7 m, and 2.0 m at University of Ghana

The highest corrected field levels for this location are 1.17447 ± 0.16841 Vm^{-1} and 1.15542 ± 0.16568 Vm^{-1} both at UHF. Field levels below 740 MHz are relatively low except for field strength resulting from FM radio transmission at 105.7 MHz. The spatial average electric field levels were plotted against their corresponding frequencies in Figure 51. The maximum power density at this site was 0.00366 W/m^2. A total of 140 sources were detected at this location. Each of the electric field strength due to a particular frequency is compliant with ICNIRP.

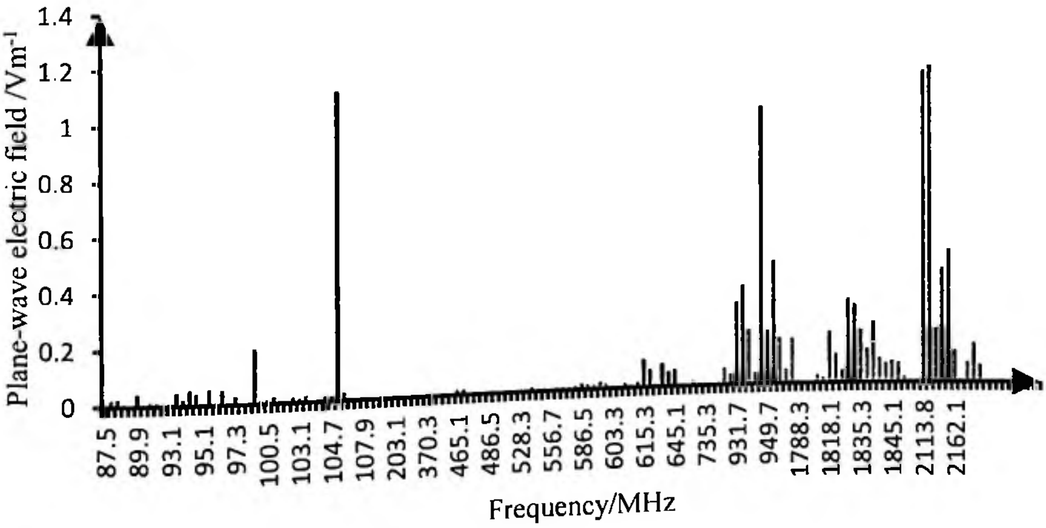

Figure 51: A Plot of E (spatial average) against Frequency for University of Ghana

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In Table A22 (in Appendix A), results from the six frequency bands were summarised. The highest fields were produced from within the UMTS (WCDMA/3G) band. At 1.0 m above ground, 925.54 ± 132.35 mVm^{-1} was estimated as the highest plane-wave electric field within the UMTS (WCDMA/3G) band. The associated power density with this maximum field strength was 2.272 ± 0.325 mW/m^2. The total exposure quotient for this location summed up to 7.70E-04. This is 0.08% of the ICNIRP compliance limit of unity. This site therefore complied with ICNIRP recommended levels.

Abeka Junction

The electric field distribution at this point of interest shows a general variation with both height and antenna orientation. Relatively high values were obtained for antenna orientations that aligned antenna elements in the vertical plane in almost all cases. Resolved field levels at the location do not exhibit any noticeable trend. Relatively high field levels occurred randomly at varied frequencies and spatial heights as shown in Figure 52.

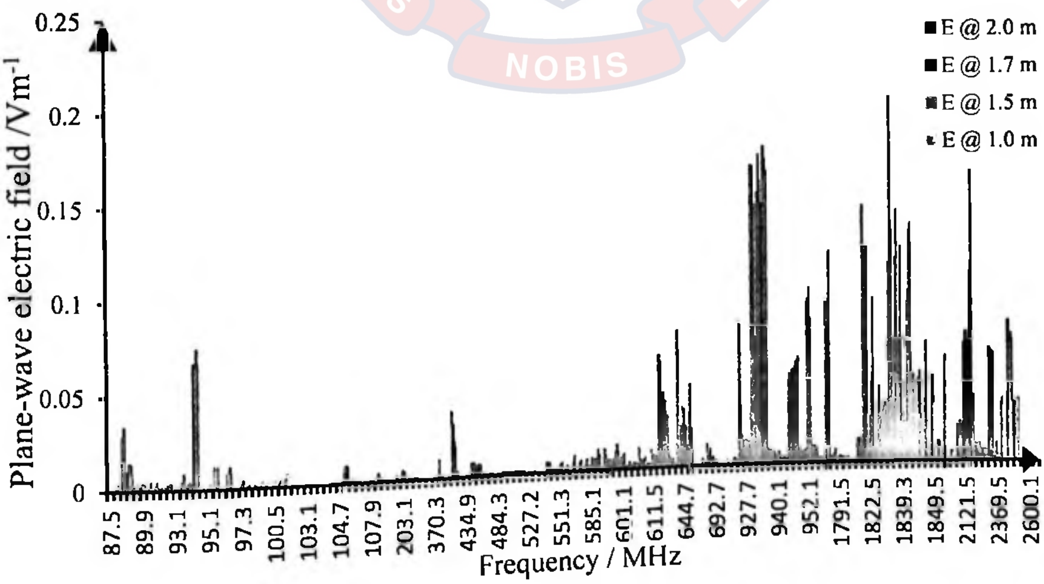

Figure 52: A Plot of Time-averaged E-fields at 1.0 m, 1.5 m, 1.7 m, and 2.0 m at Abeka Junction

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This location recorded its highest measured electric field levels at UHF at a spatial height of 1.7 m above ground level. The relatively high field levels were concentrated at frequencies used for mobile telephony and internet services. The levels ranged between 0.20227 ± 0.02917 V/m^{-1} to 0.1201 ± 0.0173 mVm^{-1}. After spatially averaging the resolved electric field values at the four spatial heights, the Abeka Junction location recorded a range of 0.2510 ± 0.0360 mV/m to 0.3313 ± 0.04778 V/m. Figure 53 shows the plot of the distribution of the spatially averaged fields over the frequency range of 87.5 MHz to 2.6 GHz. The highest power density due to the strongest field at this location is 0.29 ± 0.04 mW/m^2.

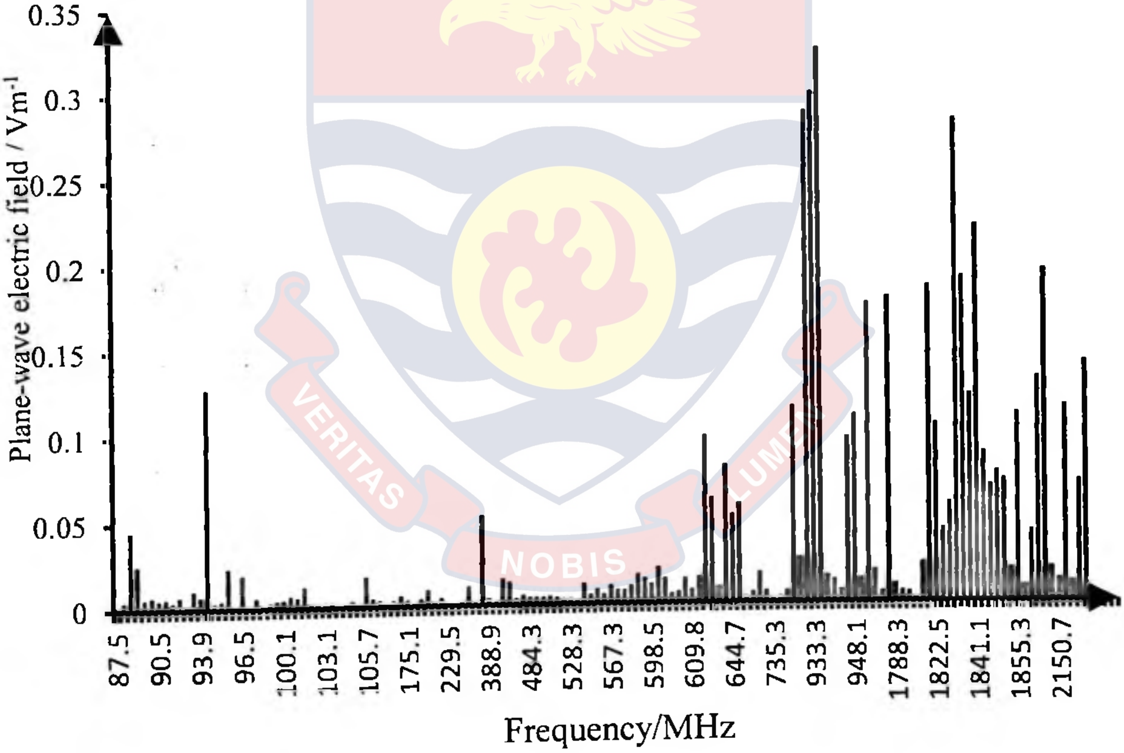

Figure 53: A Plot of E (spatial average) against Frequency for Abeka Junction

In Table A23 (in Appendix A), a summary of the numerical results for the various frequency bands was outlined. The minimum electric fields emanated from the VHF TV band. The lowest field strength was 5.06 ± 0.72 mV/m with an associated power density of 0.07 ± 0.01 μW/m². The maximum

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field strength was 414.01 ± 59.20 mV/m with power density of 454.65 ± 65.02 μW/m². The total exposure quotient at this location was 1.07E-04 representing 0.01% of the recommended limit of unity. This location therefore complies with the ICNIRP benchmarks. In all, 143 RF sources were detected at the time of carrying out this study.

Comet Hills

The levels of electric field distribution at the Comet hills site does not shows any trend of variation with either height or antenna orientation or both. Relatively high values were obtained for antenna orientations that aligned antenna elements in the vertical plane in most instances. The time-averaged electric field levels at the location do not exhibit any noticeable trend. Relatively high field levels occurred randomly at varied frequencies and spatial heights as shown in Figure 54. Almost all field levels here were below 0.2 Vm^{-1} but for those occurring at the frequencies 93.5 MHz and 609.9 MHz. A highest of 0.85442 ± 0.1196 0 Vm^{-1} was recorded at a height of 1.7 m.

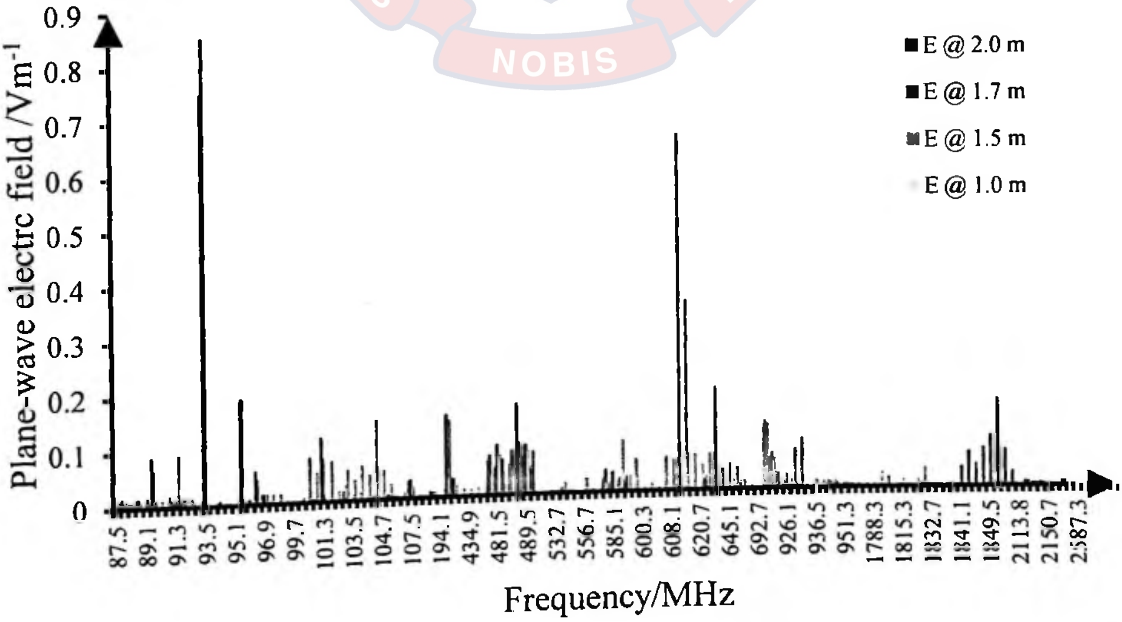

Figure 54: A Plot of Time-averaged E-fields at 1.0 m, 1.5 m, 1.7 m, and 2.0 m at Comet

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The spatial average plane-wave electric field levels plotted against frequency in Figure 55 shows that the maximum field level at this location was produced as a result of transmissions from 93.5 MHz FM radio. The value was 1.13843 ± 0.15938 V/m. The lowest field strength was 1.66 ± 0.23 mV/m. These levels are well below the limits set by ICNIRP. The power density due to the strongest field was determined to be 0.04066 ± 0.00569 W/m^2.

In Table A24 (in Appendix A), the summary of the site's numerical results for various frequency bands were displayed. The maximum spatial average electric field was produced by sources transmitting within the FM broadcast band whilst the least field level was produced from within the UMTS (WCDMA/3G).

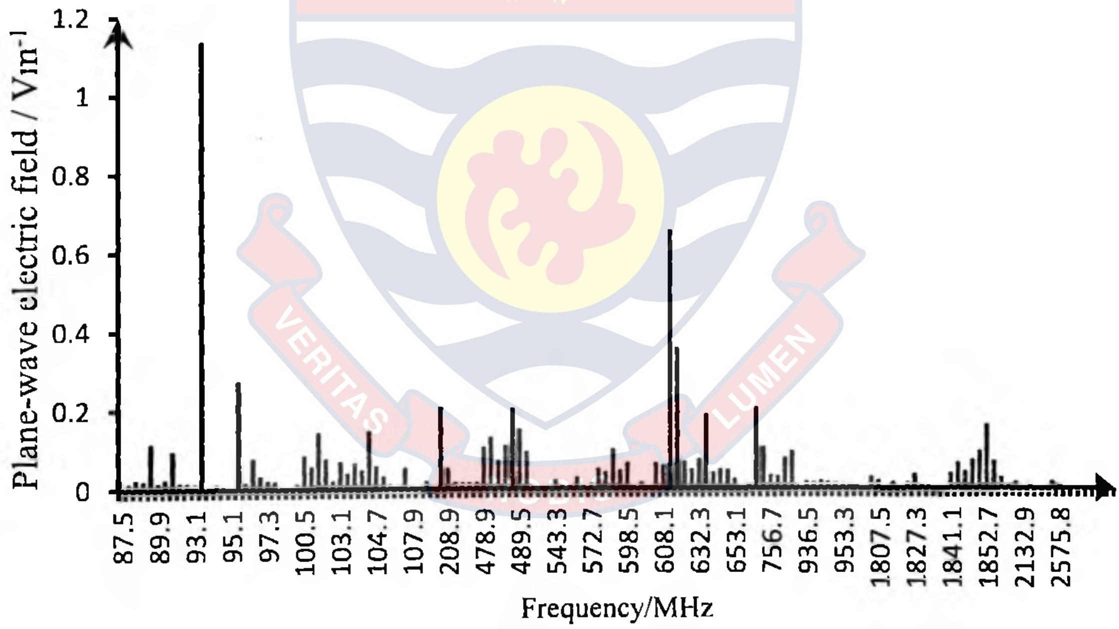

Figure 55: A Plot of E (spatial average) against Frequency for Comet.

The minimum and maximum field levels were respectively, 2.16E-02 ± 3.02E-03 mV/m and 8.34E-09 ± 1.17E-09 mV/m. The total exposure quotient for the location is 3.59E-07 ± 5.03E-08, which is 0.00006% of the limit of unity. In all, electric fields emanating from 133 RF sources were

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detected and analysed at the time of carrying out this study. This location is ICNIRP compliant.

McCarty Hill

Results indicated that electric field distribution at the point of interest varied with antenna orientation. There was no clear variation with spatial height. At 1.0 m above ground, the maximum field strength was 0.3643 ± 0.0514 Vm^{-1} at 946.5 MHz. The distribution of the field strength at 1.0 m above ground is plotted in Figure 56. Relatively high field levels were concentrated within the UHF bands. The time-averaged plane-wave electric field strength at the location is plotted in Figure 57 against their respective frequencies at the four spatial heights.

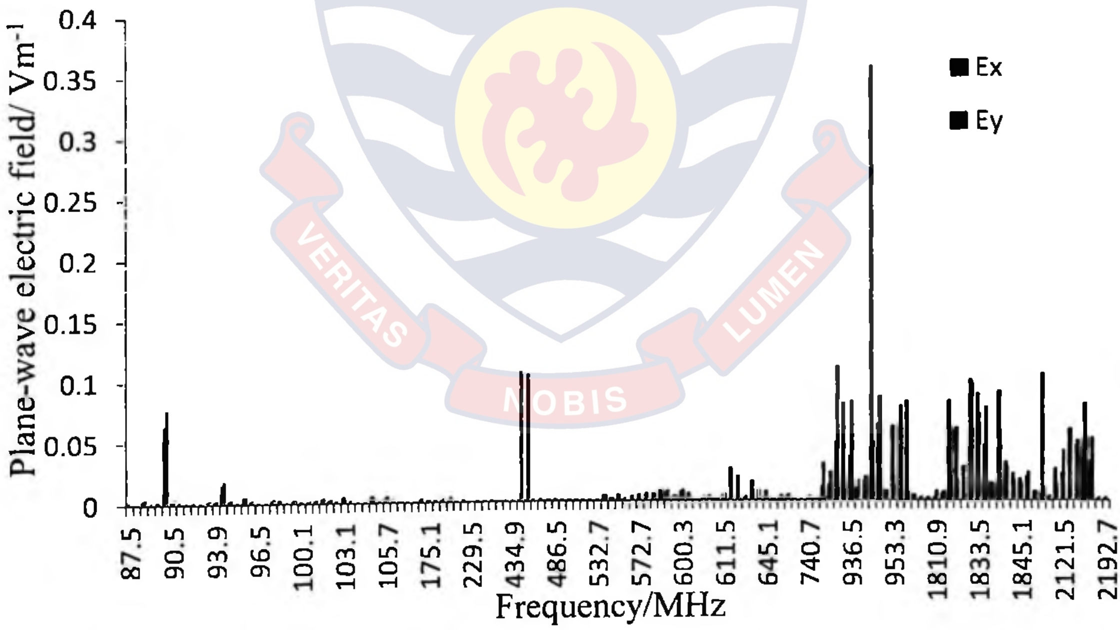

Figure 56: Plot of Electric Field against Frequency for Horizontal and Vertical Orientation of Antenna Elements at 1.0 m at McCarty Hill

The maximum field strength was determined at 1.5 m above ground. Fields emanating from FM transmissions were comparatively low, save for 89.9 MHz which produced 0.09905 ± 0.01397 Vm^{-1}. The spatial averaged

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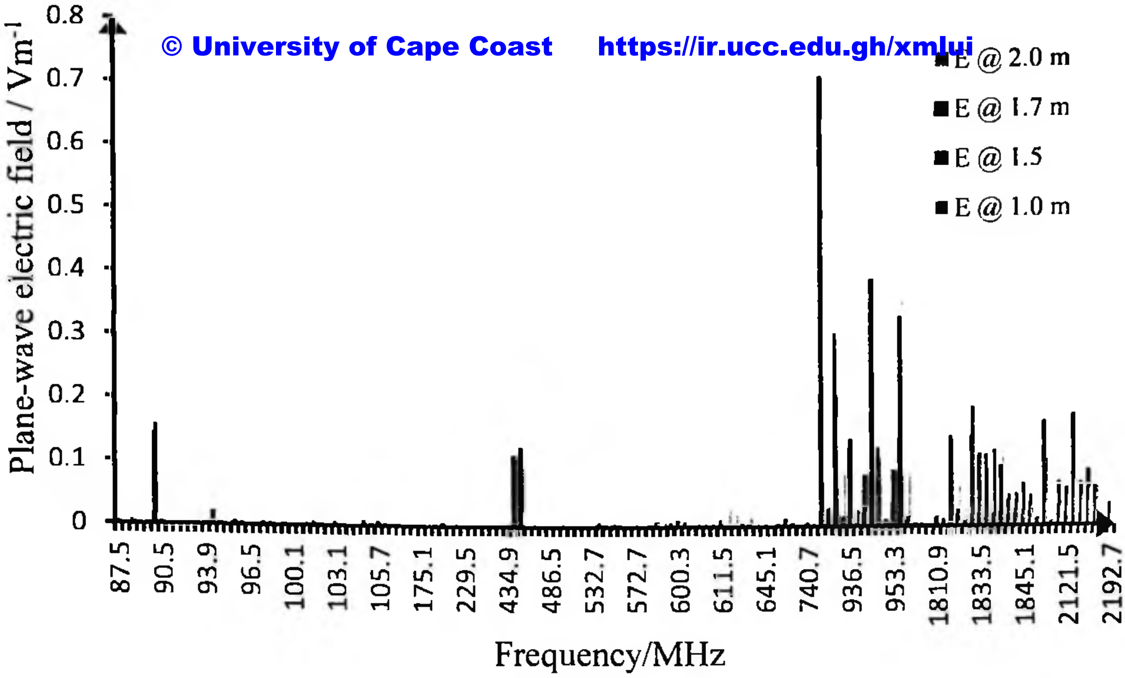

Figure 57: A Plot of Time-averaged E-fields at 1.0 m, 1.5 m, 1.7 m, and 2.0 m at McCarty Hill

electric field levels at the four spatial heights were plotted against frequency in Figure 58. The maximum field produced at this location by a single frequency to which someone is likely to be exposed was determined to be 1.035 ± 0.146 Vm^{-1} at a frequency of 926.1 MHz.

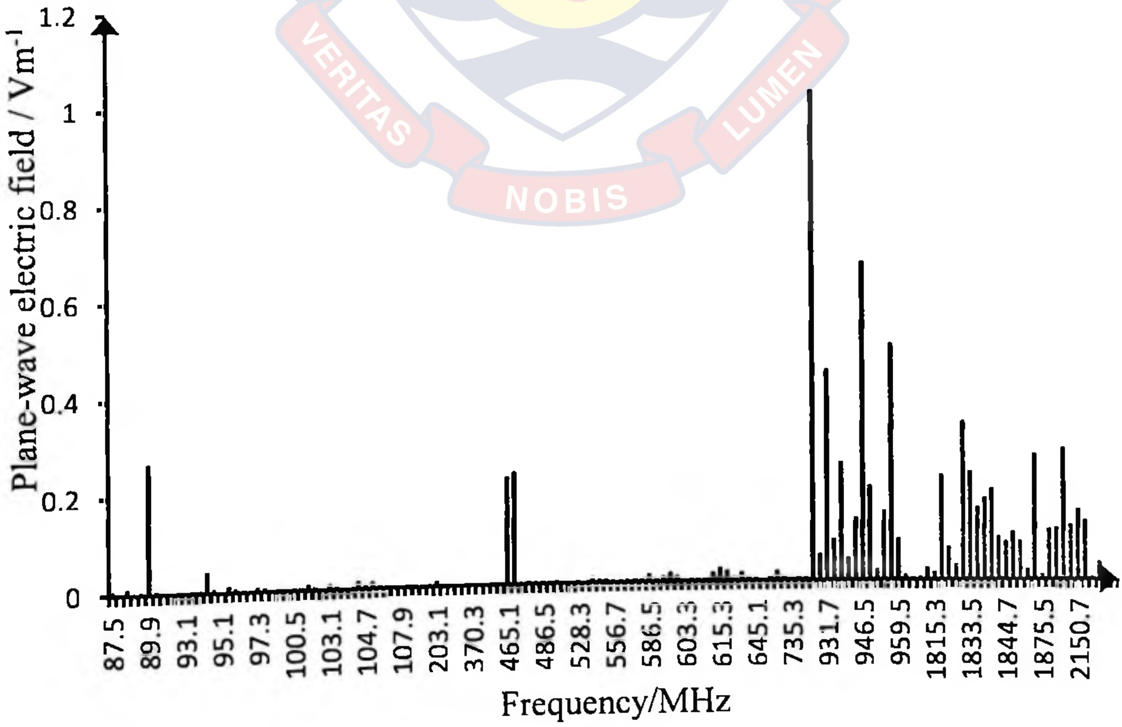

Figure 58: A Plot of E (spatial average) against Frequency for McCarty Hill

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In Table A25 (in appendix A), the numerical results for this site were summarized. GSM 900 band contributed the highest fields at this location. There was no clear pattern of variation of plane-wave electric field with spatial height. The maximum frequency-band electric field strength was 574.07 ± 80.94 mV/m with a corresponding power density of 874.15 ± 123.26 μWm^{-2}. Very low field levels were produced by sources within the VHF TV band. The total exposure quotient for this location was 6.20E-04 ± 8.80E-05 representing 0.06% of the ICNIRP recommended limit of unity. The location complied with ICNIRP levels for general public exposure

Sakumono Total Filling Station

Results from data analysed for this location show that field levels varied with antenna element orientation. About 98% of the frequencies investigated produced relatively high plane-wave electric fields when the antenna elements were aligned with the vertical plane. At 1.0 m, Figure 59 shows how these fields varied within the spectrum under investigation.

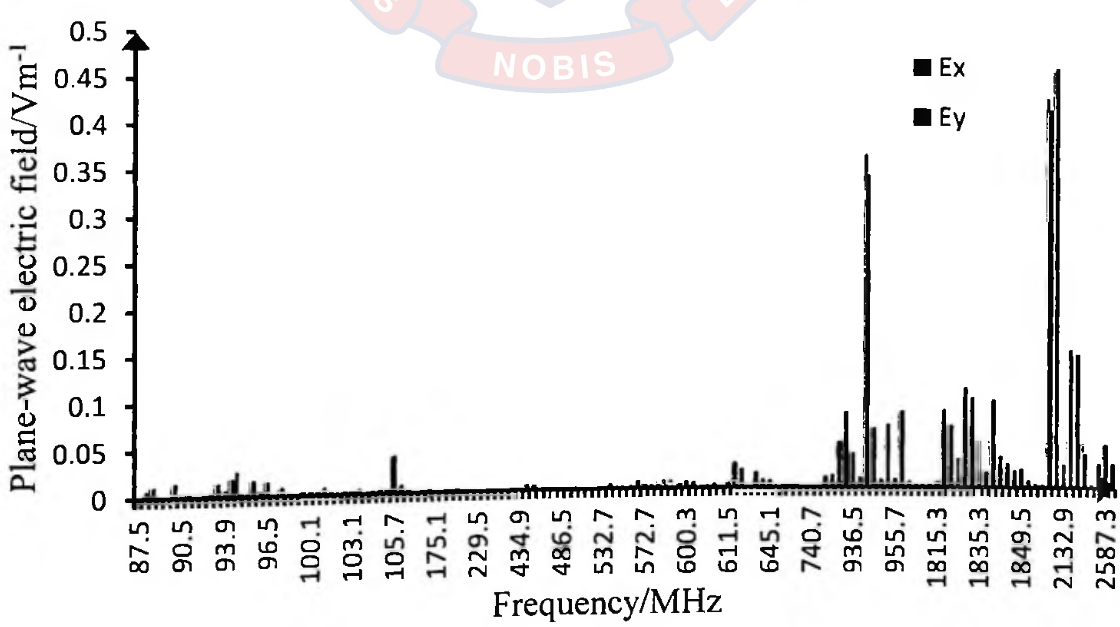

Figure 59: Variation of Electric Field Strength with Antenna Element Orientations at 1.0 m at Sakumono Total Filling Station

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The time-averaged electric field strengths at the four spatial heights as plotted in Figure 60 against their corresponding frequencies put the maximum field strength at 0.5931 ± 0.0842 Vm^{-1} at 2112.9 MHz. The spatial-averaged electric field levels for the four spatial heights were plotted against frequency in Figure 61. The highest spatial average plane-wave electric field per frequency to which someone is likely to be exposed at this location was determined to be 1.1659 ± 0.00169 Vm^{-1} at a frequency of 2113.9 MHz. This field strength has an associated power density of 3.79E-07 ± 5.39E-08 W/m^2.

In Table A26 (in Appendix A), the summary of the numerical results of data analysed for the various frequency bands was presented. The maximum frequency band spatial average electric field strength at this location was obtained at 1.0 m within the UMTS (WCDMA/3G) band.

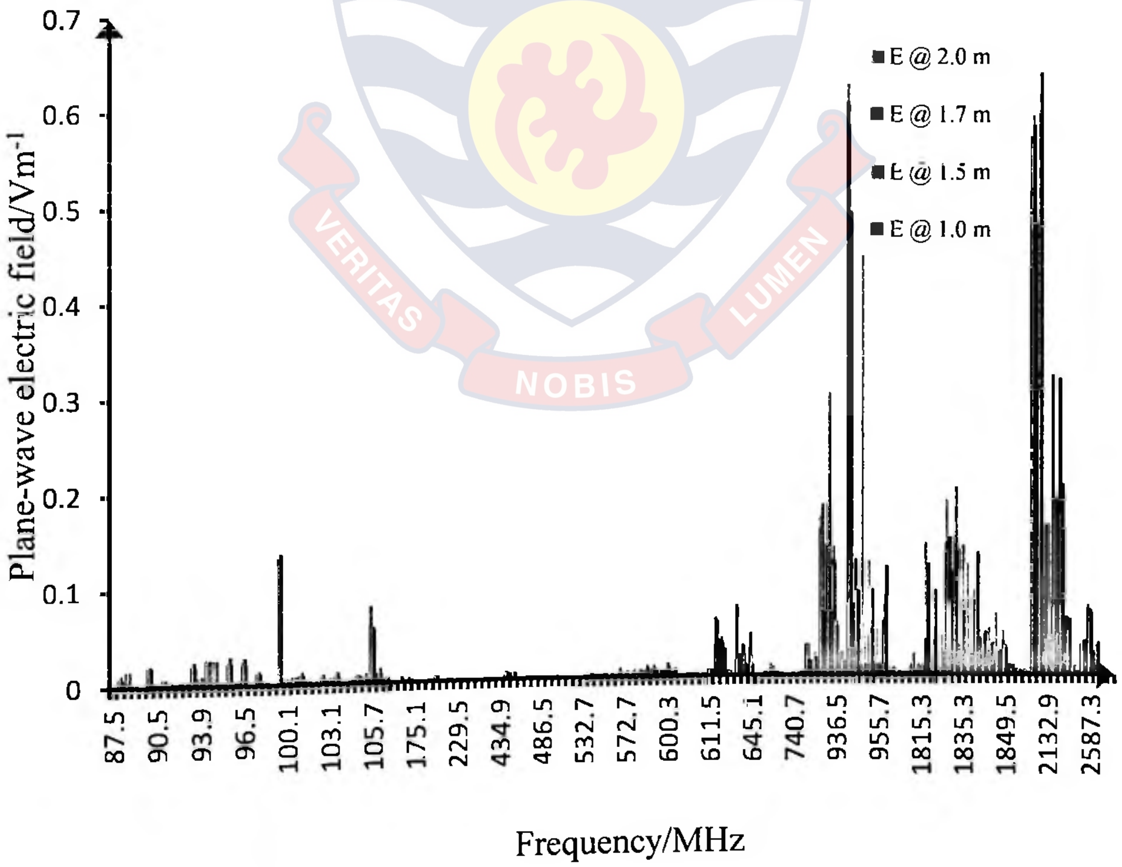

Figure 60: A Plot of Time-averaged E-fields at 1.0 m, 1.5 m, 1.7 m, and 2.0 m at Sakumono Total Filling Station

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The value was 413.85 ± 58.35 mV/m with an associated power density of
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454.30 ± 64.06 μW/m². The minimum frequency-band spatial averaged field strength at this location came from within the VHF TV band.

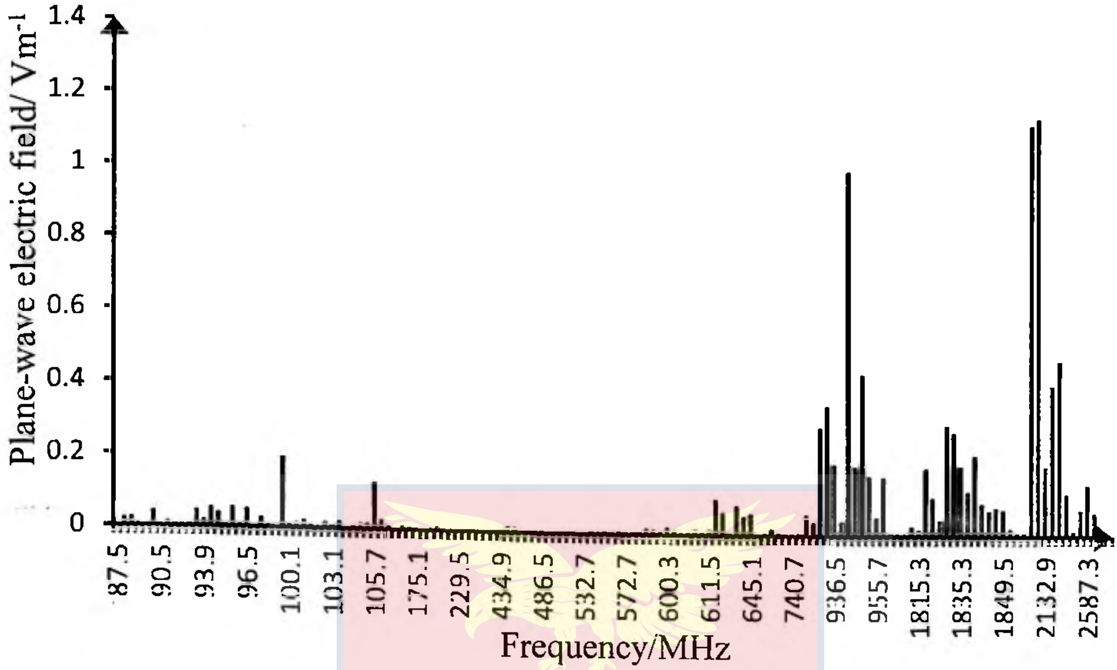

Figure 61: A Plot of E (spatial average) against Frequency for Sakumono Total Filling Station

The total exposure quotient for this location was 1.32E-04 ± 1.87E-05 representing 0.013% of the ICNIRP recommended level of unity. The location complied with ICNIRP levels for general public exposure.

Electric Field Trend at Sekondi-Takoradi Sites

Vienna City Roundabout

The results from this site show that the field strengths varied significantly as the antenna elements were rotated between the vertical and horizontal planes. With the log-periodic antenna elements aligned with the vertical plane (Ey), relatively high plane-wave electric fields strengths were obtained than in the case where same elements were aligned with the horizontal plane. In Figure 62, a plot was made of such field strengths at 1.0

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m. 98% of the highest fields occurred when the antenna elements were aligned with the vertical plane. The maximum plane-wave electric field strength at 1.0 m was 0.087 ± 0.012 Vm^{-1} at 1842.9 MHz. The concentration of relatively high field occurred within the UHF (Bands IV and V).

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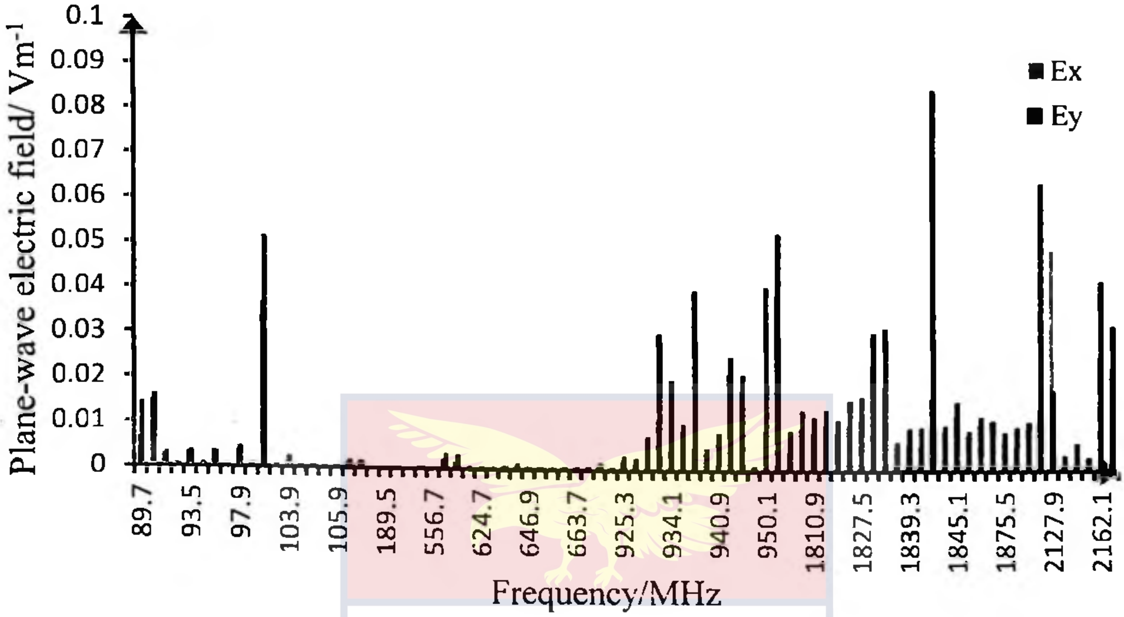

Figure 62: Variation of Electric Field Strength with Antenna Element Orientations at 1.0 m at Vienna City Roundabout

The time-averaged plane-wave electric field strength values at the four spatial heights were plotted in Figure 63. The maximum field strength was

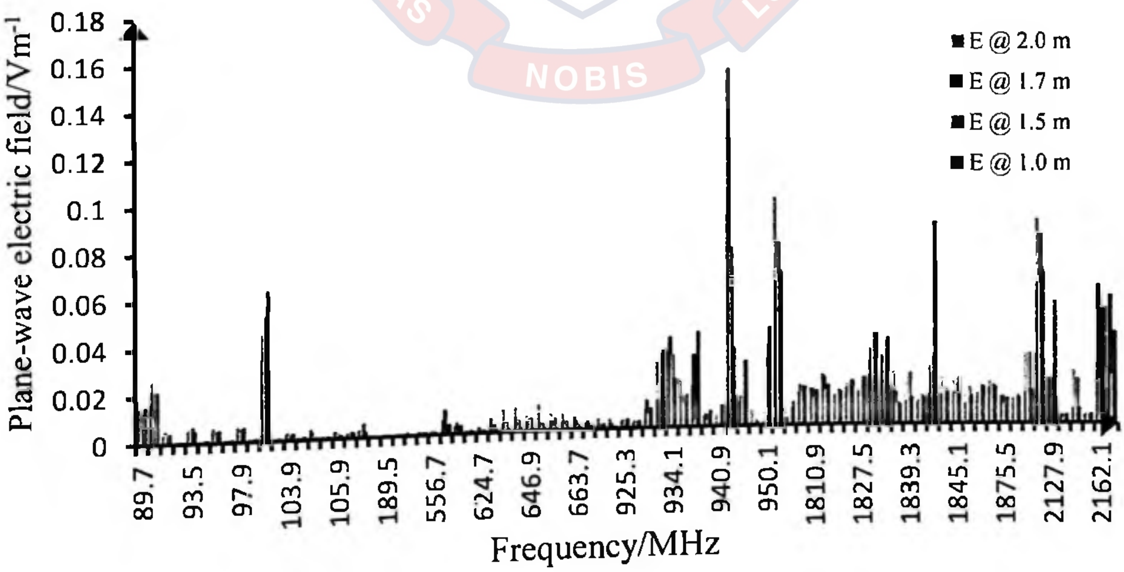

Figure 63: A Plot of Time-averaged E-fields at 1.0 m, 1.5 m, 1.7 m, and 2.0 m at Vienna City Roundabout.

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determined at 943.9 MHz to be 0.1562 ± 0.02202 Vm^{-1} at a spatial height of
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1.7 m. The time-averaged field strength did not show a clear variation with height. A plot of the spatially averaged field levels against frequency in Figure 64 showed that the maximum plane-wave field for this location was 0.2006 ± 0.0283 Vm^{-1} at 943.9 with an associated power density of 106.01 ± 14.94 μWm^{-2}. A total of 83 RF sources contributed to the field level at this location.

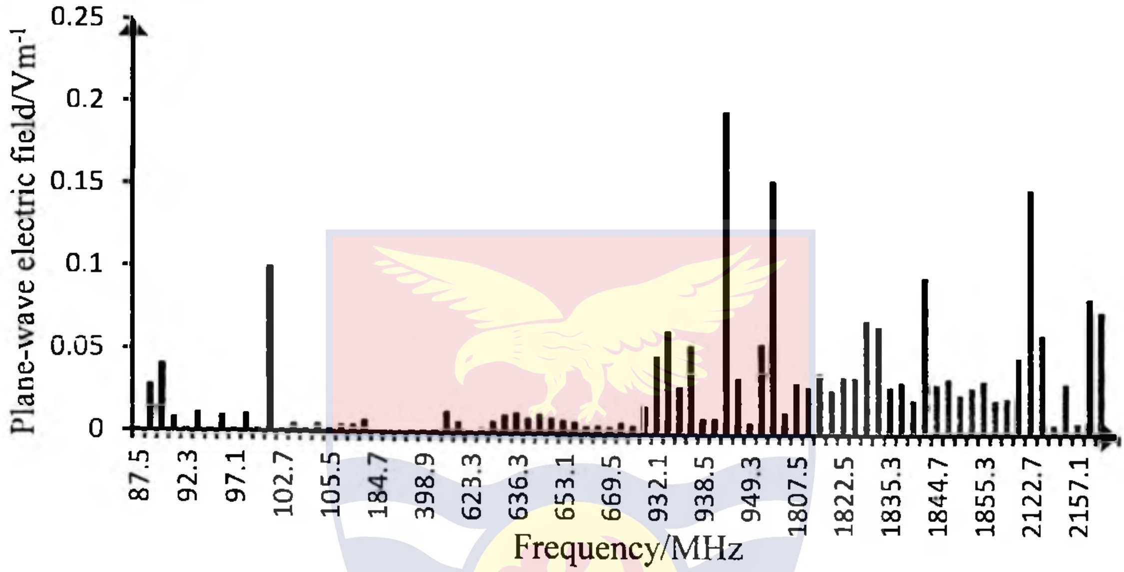

Figure 64: A plot of E (spatial average) against Frequency for Vienna City Roundabout.

Each of the electric fields due to a particular frequency is compliant with ICNIRP levels for general public exposure.

Table A27 (in Appendix A) shows the numerical results of the frequency bands for Vienna City Roundabout. The maximum spatial average electric fields came from GSM 900 band whilst VHF TV band frequencies generated the least field levels. The value of the maximum spatial average frequency-band electric field strength was 138.32 ± 19.50 mVm^{-1} at 1.7 m with a power density of 47.686 ± 6.723 μW/m². The minimum was 1.09 ± 0.15 mVm^{-1} at 1.0 m with an associated power density of 0.0031 ± 0.0004 μW/m². The total exposure quotient for this site was 2.05E-05 ± 2.89E-06.

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The exposure at this location complied with ICNIRP recommended levels for public exposure.

Takoradi Technical University

The results from data analysed for this location showed that there was variation of electric field strength with antenna element orientation. The plane-wave electric field distribution at 1.0 m above the ground at this location is plotted in Figure 65. Relatively high field levels occurred when the stacked antenna elements of the log-periodic antenna were aligned in the vertical planes. The maximum plane-wave electric field strength measured at this location was 0.06552 ± 0.00926 Vm^{-1} at 2122.7 MHz. The difference in the field strength levels at 2122.7 MHz, with antenna elements aligned with the vertical and horizontal planes, was 0.05144 ± 0.00727 Vm^{-1}.

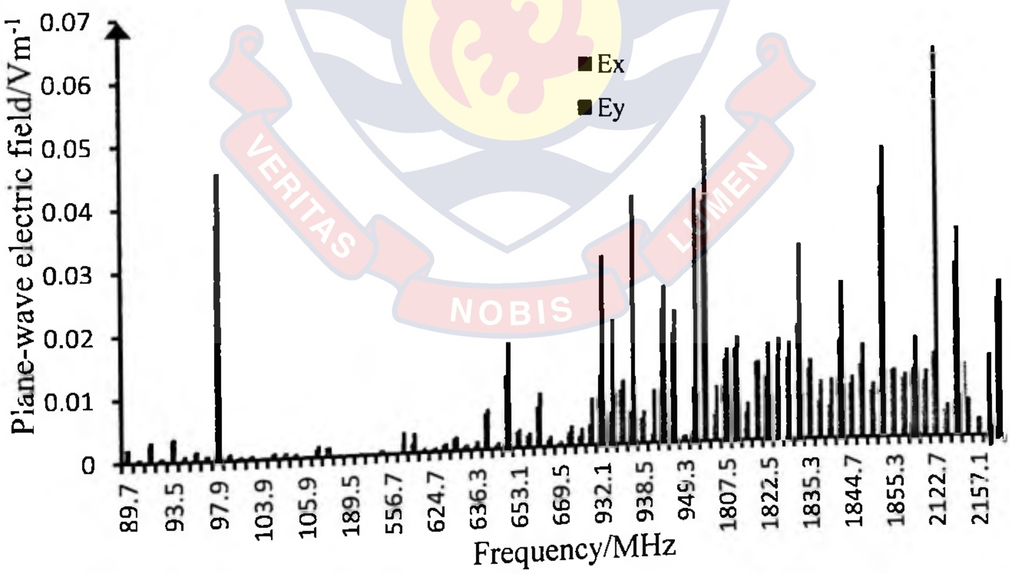

Figure 65: Variation of Electric Field Strength with Antenna Element Orientations at 1.0 m at Takoradi Technical University.

The time-averaged plane-wave electric field strength for this location at the relevant spatial heights was plotted in Figure 66.

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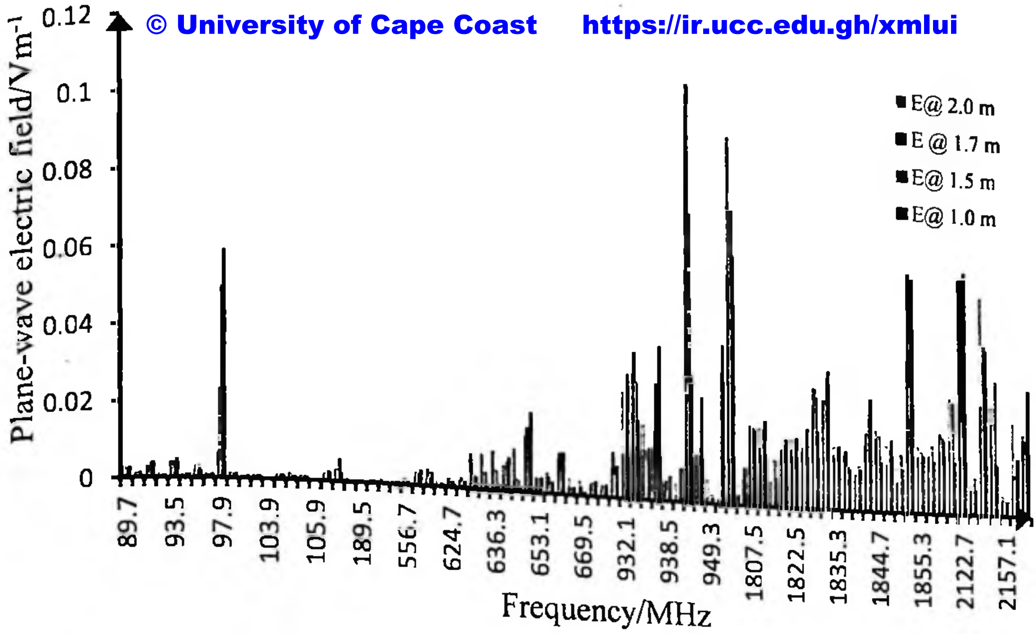

Figure 66: A Plot of Time-averaged E-fields at 1.0 m, 1.5 m, 1.7 m, and 2.0 m at Takoradi Technical University site.

The maximum field strength was determined at 1.7 m above ground level to be 0.1126 ± 0.0159 Vm^{-1} at 943.9 MHz followed closely at 2.0 m by 0.09964 ± 0.01409 Vm^{-1} at 952.5 MHz. About 53% of the relatively high field strengths occurred at a spatial height of 1.0 m above ground. Figure 67 shows the plot of the spatial averaged plane-wave electric field strength for the Takoradi Technical University location.

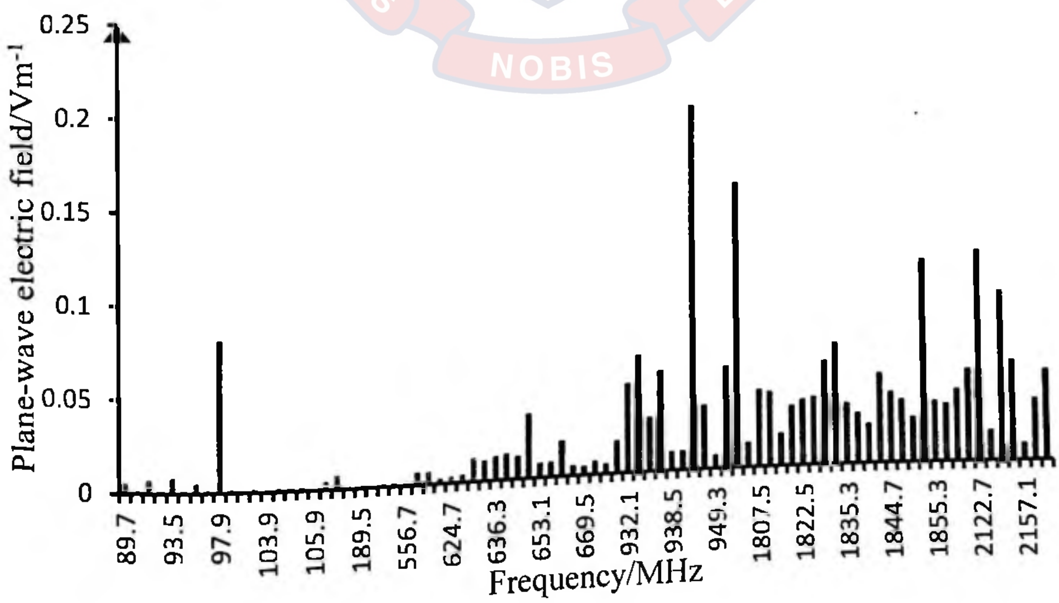

Figure 67: A Plot of E (spatial average) against Frequency for Takoradi Technical University

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This location has relatively low electric field contributions from FM radio transmissions as well as from VHF TV transmissions. The maximum spatially averaged electric field strength for this location was 0.20006 ± 0.02829 Vm^{-1}. Plane-wave electric field strength from UHF was predominant at this site. The maximum power density at this site is 0.000106 ± 0.00399 W/m^2. A total of 83 RF sources contributed electric field strength at this location.

In Table A28 (in Appendix A), a summary of the numerical results for band frequencies at this location was presented. The minimum band plane-wave electric field strength occurred within the VHF TV band at 1.0 m above ground with a value of 2.24 ± 0.32 mV/m. The associated power density estimate was 0.01 ± 0.001 $\mu W/m^2$. The maximum band spatial average electric field level was 231.85 ± 32.69 mV/m at 1.0 m within the UMTS (WCDMA/3G) band. The total exposure quotient at this location was 0.0240 ± 0.0034. The general public exposure at this location complied with ICNIRP recommended levels.

Anaji West Line

In Figure 68, the plane-wave electric field strength detected at 1.0 m above ground level was plotted against the contributing frequencies at the Anaji West Line location. Analysis of data from measurement at this location revealed that there is significant variation in the levels of the plane-wave electric field strength when the antenna elements of the log-periodic antenna were aligned with the horizontal and vertical planes.

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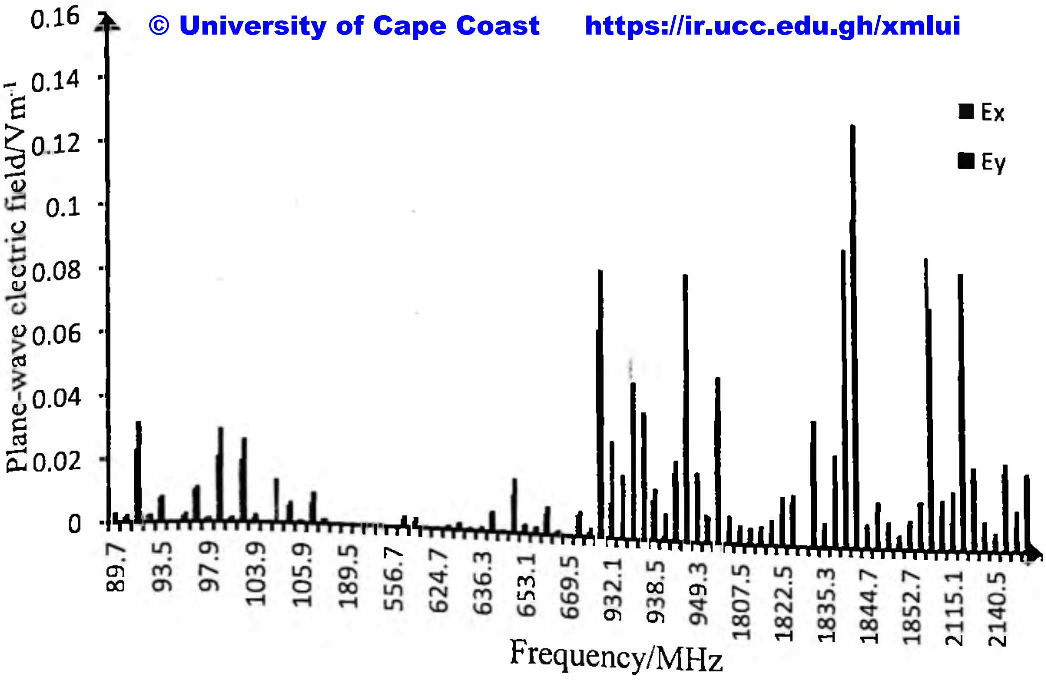

Figure 68: Variation of Electric Field Strength with Antenna Element Orientations at 1.0 m at Anaji West Line.

About 97% of the maximum fields strength occurred when the antenna element were aligned with the vertical plane. The highest field level at 1.0 m was 0.1406 ± 0.1991 Vm^{-1}. The time-averaged plane-wave electric field strength, calculated for each spatial height investigated, was plotted against their respective frequencies in Figure 69.

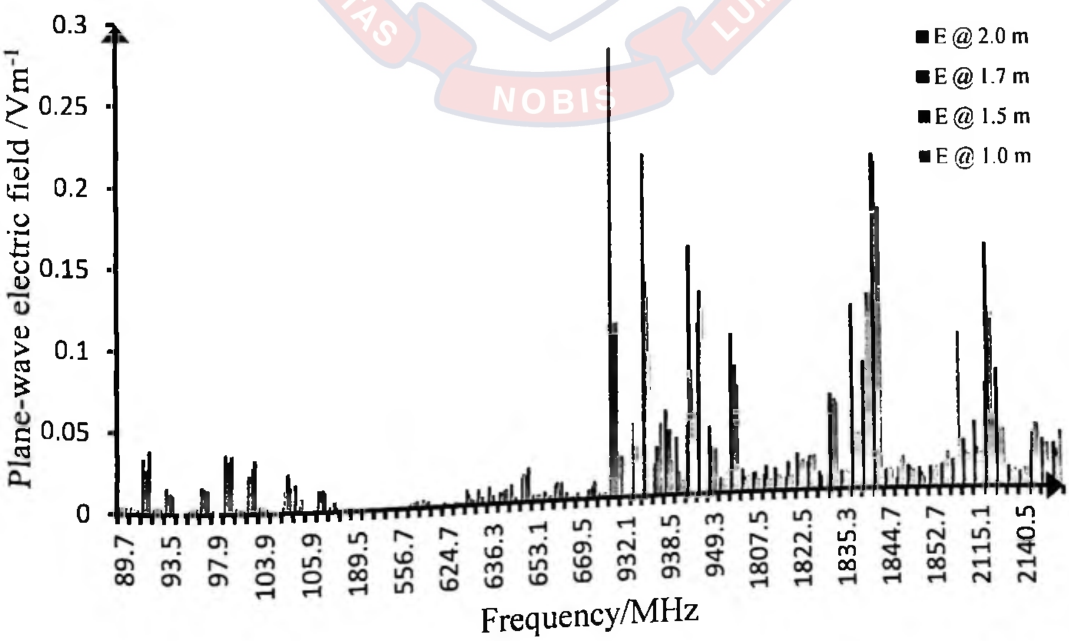

Figure 69: A Plot of Time-averaged E-fields at 1.0 m, 1.5 m, 1.7 m, and 2.0 m at Anaji West Line site

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Results did not show a reliable variation of field strength with spatial heights. However, the maximum time-averaged plane-wave electric field strength was determined at 2.0 m above ground to be 0.2817 ± 0.0407 Vm^{-1} with an associated power density of 210.1 ± 29.7 μWm^{-2}. Electric fields produced at this location as a result of transmissions from FM radio stations were relatively low. The highest electric field strength due to FM transmissions was 13.7% of the maximum field calculated for this location. The relatively high field levels were concentrated at UHF bands. The spatial-averaged electric field strength of levels from the four spatial heights was plotted against frequency in Figure 70.

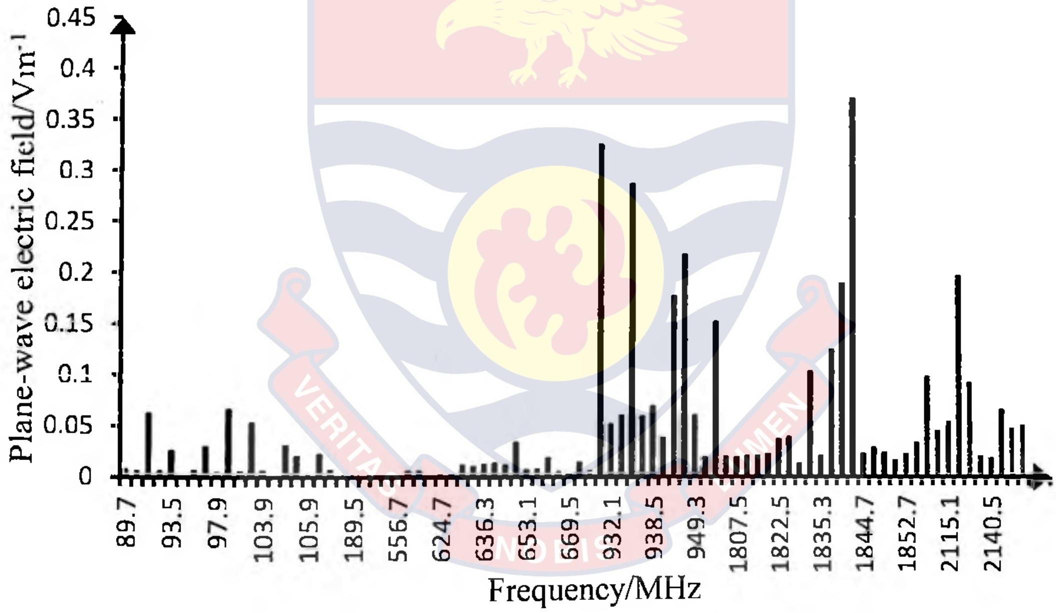

Figure 70: A Plot of E (spatial average) against Frequency for Anaji West Line

The highest field per frequency to which someone is likely to be exposed to at this location was determined to be 0.38868 ± 0.05620 Vm^{-1} at a frequency of 1842.9 MHz with an equivalent power density of 400.01 ± 057.84 μWm^{-2}. The location complied with ICNIRP levels for general public exposure in terms of electric field strengths from individual frequencies as well as from frequency bands.

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Table A29 (in Appendix A) displays the summary of the numerical results for frequency groupings at this location. Spatial average field contributions from the VHF TV are the lowest at this location. The minimum value was 2.24 ± 0.32 Vm^{-1} at a spatial height of 1.0 m above ground. This electric field level produced the lowest power density of 0.01 ± 0.002 μWm^{-2}. At 2.0 m above ground within the GSM 900 band, the maximum frequency band spatial average electric field was 397.44 ± 56.28 Vm^{-1} with an associated power density of 418.99 ± 59.329 μWm^{-2}. The total exposure quotient for this location was 8.05E-05 ± 1.14E-05. The location complied with the ICNIRP recommended levels.

Galaxy Aben Be Bong

Results showed that the plane-wave electric field strength were highest while the antenna elements were aligned with the vertical plane (Ey). In Figure 71, a plot was made of field strength levels measured in the vertical and horizontal planes against their respective frequencies at a spatial height of 1.0 m above ground. The highest instantaneous field strength value was 0.0555 ±

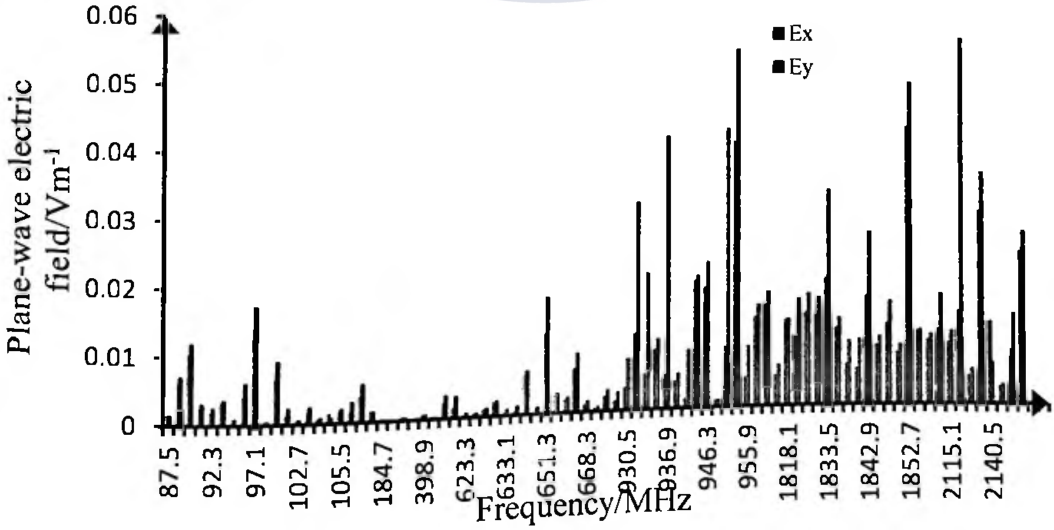

Figure 71: Variation of Electric Field Strength with Antenna Element Orientations at 1.0 m at Galaxy Aben Be Bong site.

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0.00785 Vm^{-1} at 2122.7 MHz. The relatively high field strength occurred at UHF band. The difference in value of the plane-wave electric field strength in the two planes at 2122.7 MHz was 0.041 ± 0.005 Vm^{-1}. The time-averaged plane-wave electric field strength distribution at the various spatial heights was plotted in Figure 72. The maximum plane-wave time-averaged electric field strength determined for this location was 0.1263 ± 0.0179 Vm^{-1} at a height of 1.7 m above ground. This maximum field was due to transmissions at 943.9 MHz.

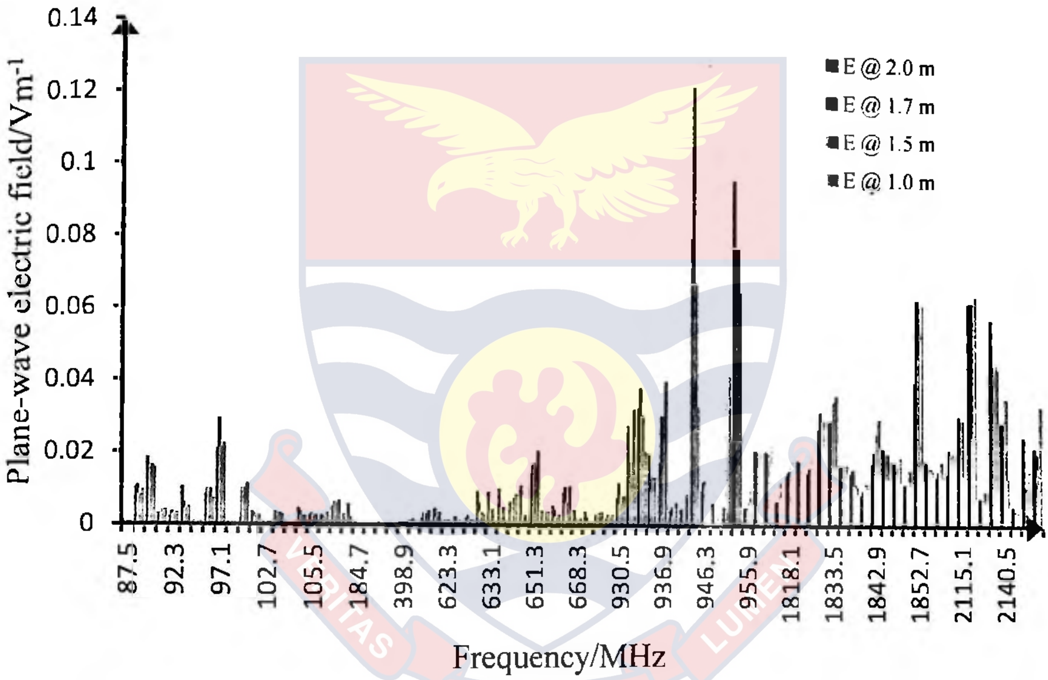

Figure 72: Plot of Time-averaged E-fields at 1.0 m, 1.5 m, 1.7 m, and 2.0 m at Galaxy Aben Be Bong site.

About 97% of the calculated time-averaged field strength was below 0.1 Vm^{-1}. In Figure 73, a plot was made of the spatial-averaged plane electric field against frequency for the Galaxy Aben Be Bong location. At this location, the relatively high spatial-averaged plane-wave electric fields were predominant at frequencies above 930 MHz. The highest field at this location was due to transmissions at 943.9 MHz and had the value of 0.1987 ± 0.0281 Vm^{-1}. The number of RF sources detected at this location at the time of

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assessment was 84. The highest power density due to the strongest field at this location is 0.104 ± 0.014 mW/m^2.

Table A30 (in Appendix A) displays the summary of the numerical results for each frequency band investigated at this location. The VHF TV band produced the minimum spatial averaged electric field at a height of 1.0 m. the value was 2.23 ± 0.32 mVm^{-1} with an associated power density of 0.011 ± 0.002 μW/m².

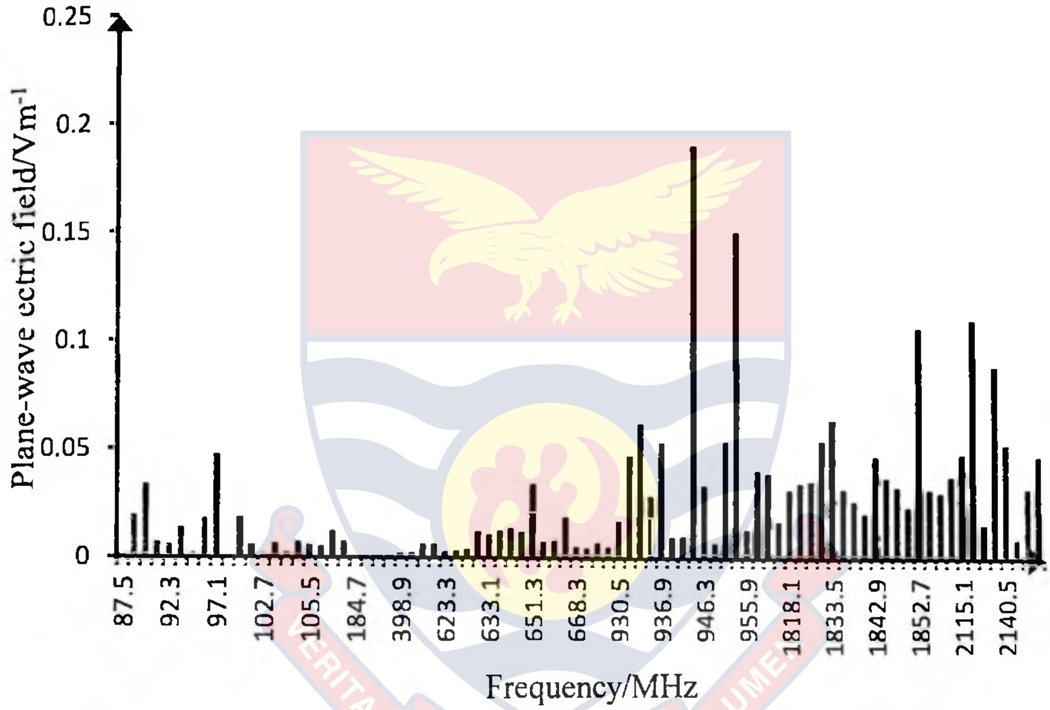

Figure 73: A Plot of E (spatial average) against Frequency for Galaxy Aben Be Bong site.

The maximum spatial average frequency-band electric field strength was 331.85 ± 46.92 mVm^{-1} at 1.0 m above the ground within the UMTS (WCDMA/3G) band. The power density produced by this field level was 292.11 ± 41.30 μW/m². The total exposure quotient for this location was 2.47E-05 ± 3.49E-06. Exposure at this location complied with ICNIRP levels for public exposure.

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The distribution of plane-wave electric field strength at the Lagos town location did not exhibit any trend of variation with measurement height. However, antenna element orientation affected the measurement results significantly. Relatively high electric field values were obtained for antenna orientations that aligned antenna elements in the vertical plane. The electric field levels here were below 0.1 Vm^{-1}. The highest electric field detected at this location was of 0.055 ± 0.007 Vm^{-1} emanating from transmissions at 2122.7 MHz. The detailed distribution of electric field strength at 1.0 m above ground was plotted in Figure 74. Electric field due to FM transmissions was very low at this location. However, fields from the UHF band were relatively high.

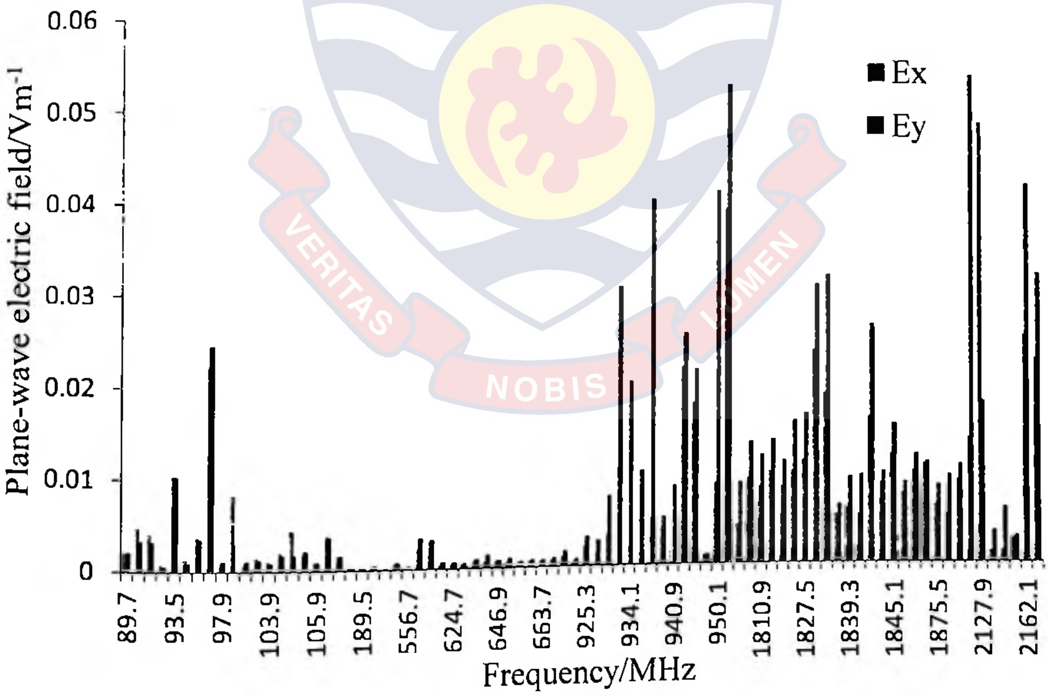

Figure 74: Variation of Electric Field Strength with Antenna Element Orientations at 1.0 m at Lagos Town site.

The time-averaged electric field strengths at the four spatial heights as plotted in Figure 75 against their corresponding frequencies showed that the

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maximum field strength of 0.1122 ± 0.0159 Vm^{-1} at 943.9 MHz at a spatial height of 1.7 m . Here again, the relatively high time-averaged plane-wave electric fields strengths were concentrated within the UHF band.

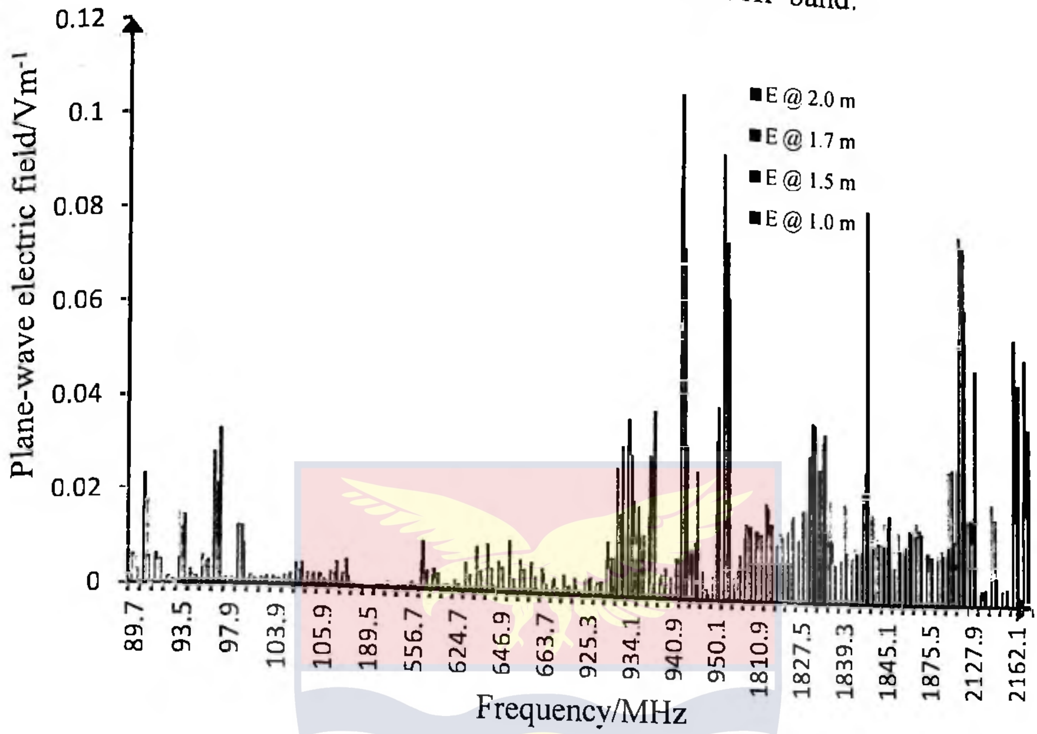

Figure 75: A Plot of Time-averaged E-fields at 1.0 m, 1.5 m, 1.7 m, and 2.0 m at Lagos Town site.

A plot of the spatial-averaged plane-wave electric field strength distributions for the Lagos Town site is displayed in Figure 76. The maximum electric field per frequency was 0.1865 ± 0.0263 Vm^{-1}. This field strength was due to transmissions at 943.9 MHz. Each of the electric fields due to a particular frequency is compliant with ICNIRP levels for general public exposure. A total of 82 RF sources contributed to the field level at this location. From frequency band analysis summarised in Table A31 (in Appendix A), VHF TV band frequencies contributed the minimum fields. An average of 3.51 ± 0.50 Vm^{-1} came from the band. GSM 900 and UMTS (WCDMA/3G) bands produced the relatively high field levels of similar magnitude and order.

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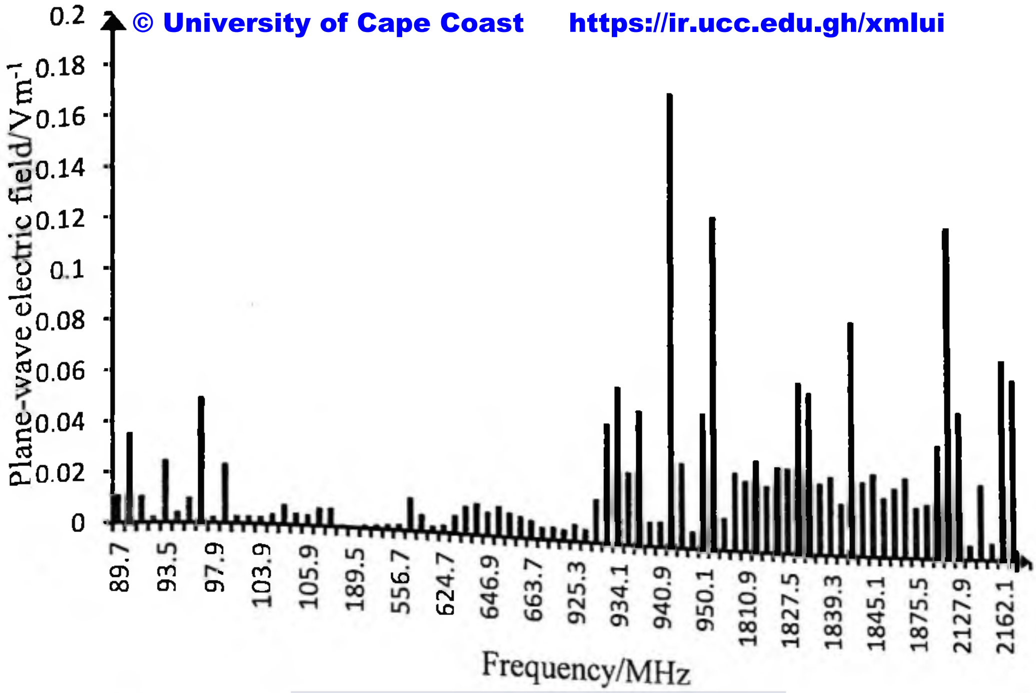

Figure 76: A Plot of E (spatial average) against Frequency for Lagos Town site.

The maximum spatial average frequency band electric field was 331.85 ± 46.96 Vm^{-1} at 1.0 m above ground within the UMTS (WCDMA/3G) band. The total exposure quotient for the location was 2.44E-05 ± 3.45E-06. This location complied with ICNIRP recommended limits.

Fort Orange

Results indicated that the electric field distribution at the point of interest varied with both height and antenna orientation. Relatively high values were obtained for antenna orientations that aligned antenna elements with the vertical plane. At a height of 1.0 m above the floor (Figure 77), relatively high electric field values were obtained within the UHF band. The maximum plane-wave electric field strength was obtained at 1851.7 MHz to be 0.1508 ± 0.0214 Vm^{-1}. There was not much difference between the two field values obtained when the antenna elements were aligned with the vertical and

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horizontal planes. At the frequency where the highest field occurred, the difference was 0.01659 ± 0.00235 Vm^{-1}. In a plot of the time-averaged plane-

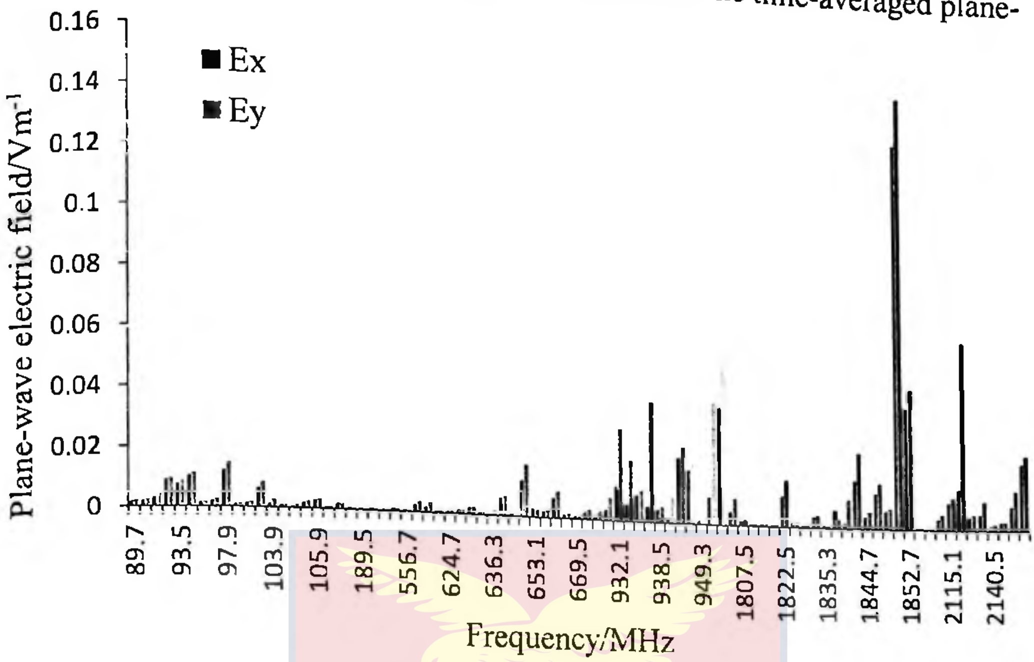

Figure 77: Variation of Electric Field Strength with Antenna Element Orientations at 1.0 m at Fort Orange.

wave electric field strengths against their corresponding frequencies in Figure 78, the two highest field strengths were determined at 1.7 m above ground.

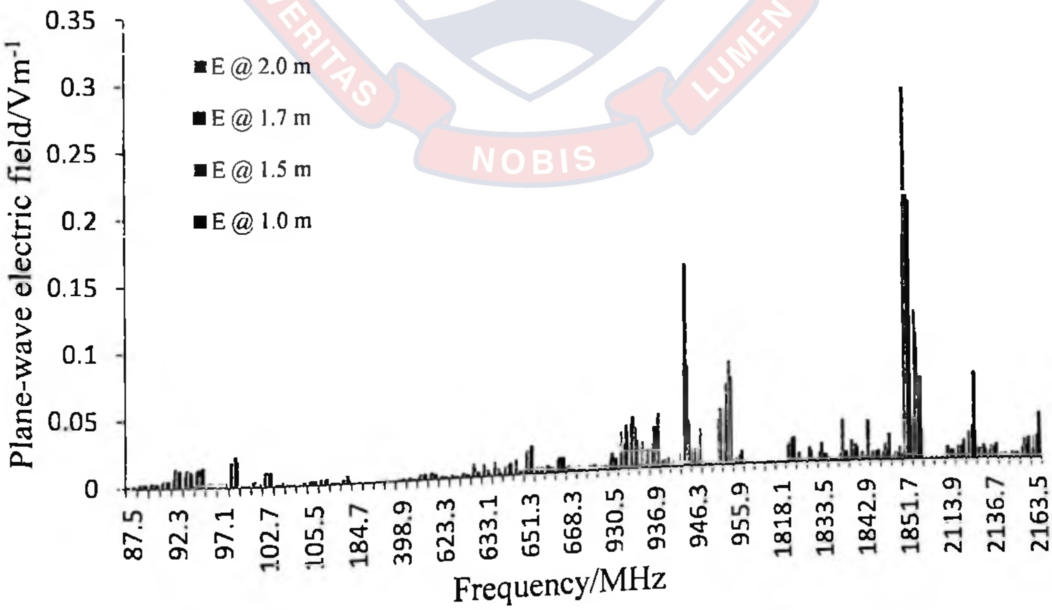

Figure 78: A Plot of Time-averaged E-fields at 1.0 m, 1.5 m, 1.7 m, and 2.0 m at Fort Orange.

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The maximum time averaged field strength was 0.2915 ± 0.0413 Vm^{-1} at a frequency of 1851.7 MHz. At 1.5 m above ground, the highest field strength equally was determined at 1851.7 MHz to be 0.2093 ± 0.0297 Vm^{-1}. Electric fields from a total of 103 sources were detected at this location. In Figure 79, a plot was made of the spatial-average plane-wave electric fields against frequency. The highest field of 0.4478 ± 0.0636 Vm^{-1} was determined at 1851.7 MHz. Table A32 (in Appendix A) shows a summary of the numerical results for the frequency bands. Overall, fields emanating from VHF TV frequencies were relatively very low. The minimum frequency band electric field was 1.24 ± 0.18 mVm^{-1}. GSM 900,

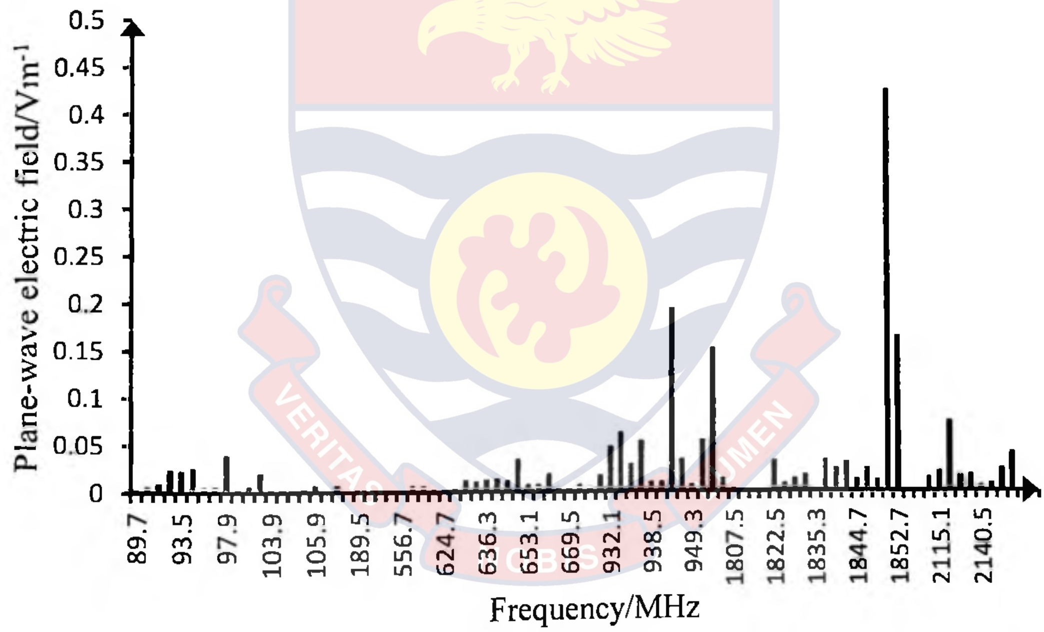

Figure 79: A Plot of E (spatial average) against Frequency for Fort Orange.

GSM 1800 and UHF TV bands contributed significantly to the total electric field strength at this location. The maximum electric field level within the bands was 321.33 ± 45.63 mVm^{-1}. The estimated power density associated with this field strength was 273.88 ± 38.89 $\mu W/m^2$. Each of the electric field due to a particular frequency is compliant with ICNIRP levels for general public exposure. The

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total exposure quotient at this location was 6.09E-05 ± 8.65E-06. This location therefore complied with ICNIRP

Essipong

Results indicated that there are variations between the field levels and antenna element orientations. Relatively high field strength values were obtained with the antenna elements aligned with the vertical plane. Figure 80 shows the plot of the distribution of plane-wave electric field at a spatial height of 1.0 m for the two orientations of the antenna elements.

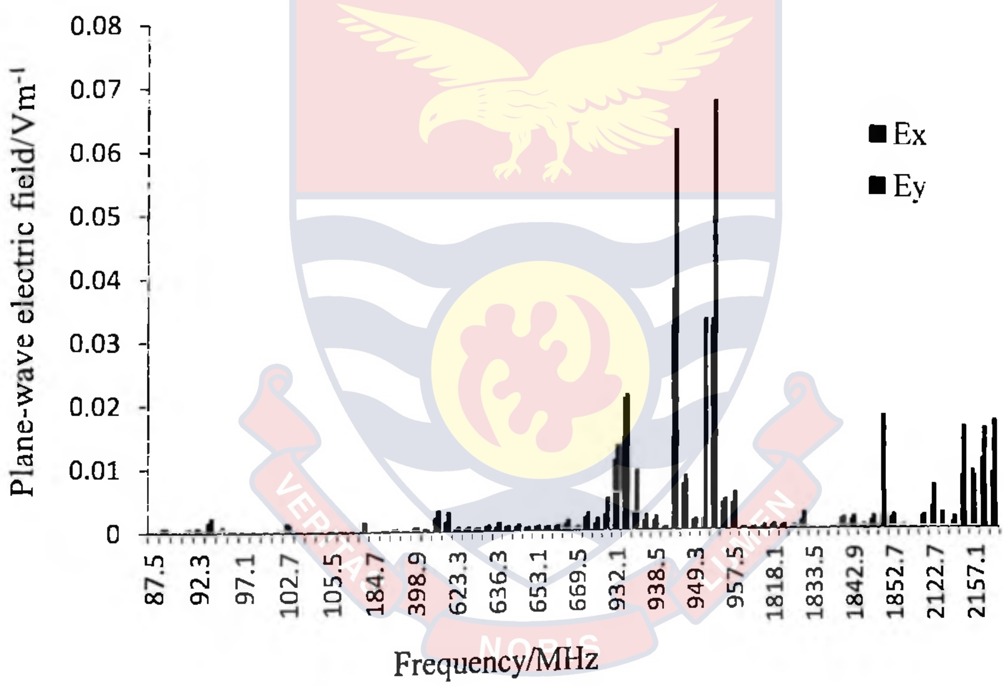

Figure 80: Variation of Electric Field Strength with Antenna Element Orientations at 1.0 m at Essipong

Relatively high field levels occurred when the stacked antenna elements of the log-periodic antenna were aligned in the vertical planes. The maximum plane-wave electric field strength measured at this height was 0.072 ± 0.010Vm^{-1} at 952.5 MHz. The difference in the field strength levels at 952.5 MHz, with antenna elements aligned with the vertical and horizontal planes, was 0.036 ± 0.005 Vm^{-1}. This value is quite significant compared with fields

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due to FM radio transmissions which were very low at this same height. The time-averaged plane-wave electric field strength for this location at the relevant spatial heights was plotted in Figure 81.

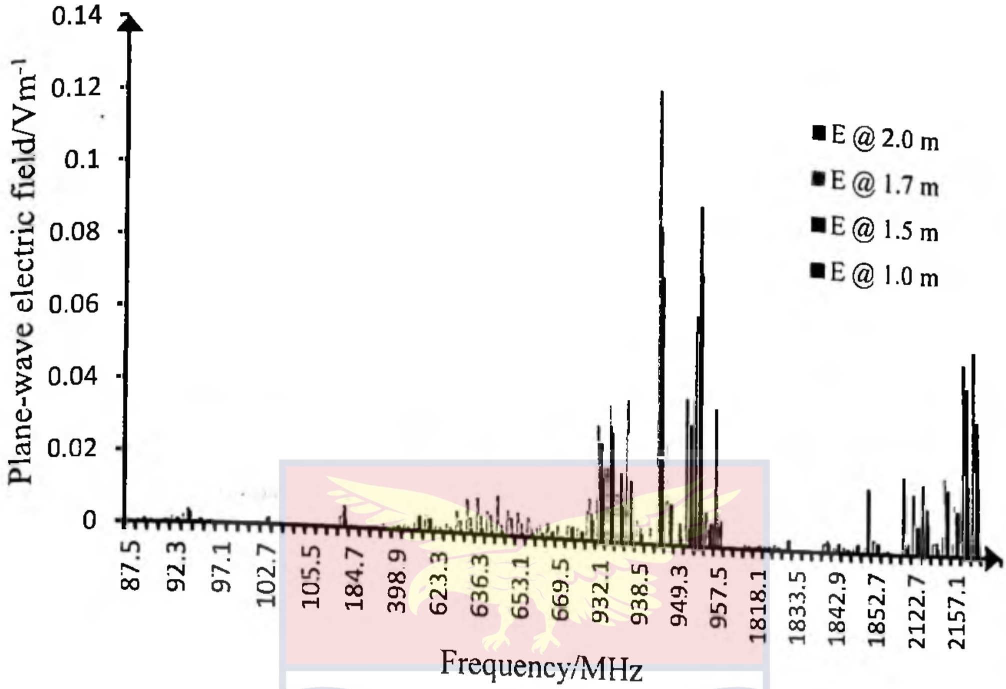

Figure 81: A Plot of Time-averaged E-fields at 1.0 m, 1.5 m, 1.7 m, and 2.0 m at Essipong.

The higher field strength was predominant within the 900 MHz band used for mobile telephony. The maximum time-averaged plane-wave electric field strength for this location was determined at 1.7 m to be 0.132 ± 0.019 Vm^{-1} from the frequency 943.9 MHz. At 1.5 m above ground, the highest time-average electric field was 0.099 ± 0.014 Vm^{-1} at 952.5 MHz. FM radio transmissions produced relatively low field strengths at all the spatial heights investigated.

In Figure 82, the spatial-averaged plane-wave electric field distributions at the Essipong location was plotted against the frequencies they originated from. For the Essipong location, the spatial averaged electric fields

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were all below 0.2 Vm-1. The highest field value was 0.197 ± 0.028 Vm^{-1} originating from 943.9 MHz.

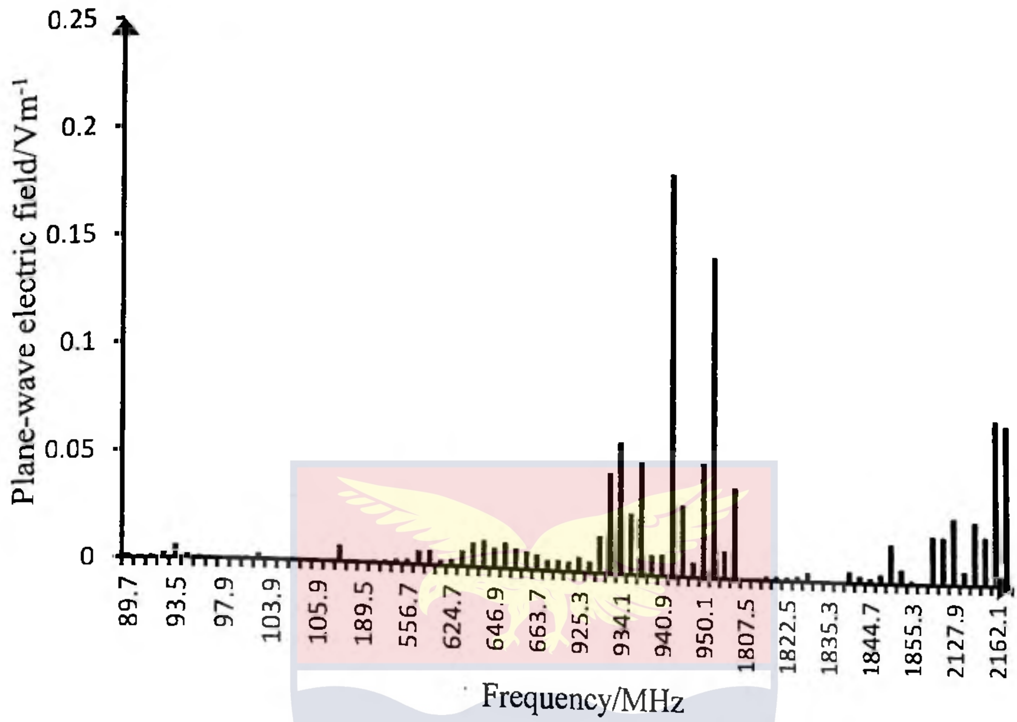

Figure 82: A Plot of E (spatial average) against Frequency for Essipong

The location has very low fields from FM radio transmissions. The highest field due to an FM radio transmission was 0.0058 ± 0.0008 Vm^{-1} from 93.5 MHz. This value is 2.9 % of the maximum field calculated for a frequency at this location. A total of 82 RF sources were detected at this location.

Table A33 (in Appendix A) summarise the numerical results for frequency bands at this location. The maximum electric fields emanated from the GSM 900 bands. VHT TV band contributed the least field at this location. The highest power density estimated for this location was 273.88 ± 38.89 μW/m². The total exposure quotient was 6.09E-05 ± 8.62E-06. The location complied with ICNIRP recommended limit.

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Results from data analysed for this location show that field levels varied with antenna element orientation. About 95% of the frequencies investigated produced relatively high plane-wave electric fields when the antenna elements were aligned with the vertical plane. At 1.0 m, Figure 83 shows how these plane-wave electric fields varied within the spectrum 87.5 MHz – 2.6 GHz. The highest plane-wave electric field was recorded at 952.5 MHz with a value of 0.06181 ± 0.008913 Vm^{-1} with antenna elements aligned with the vertical plane.

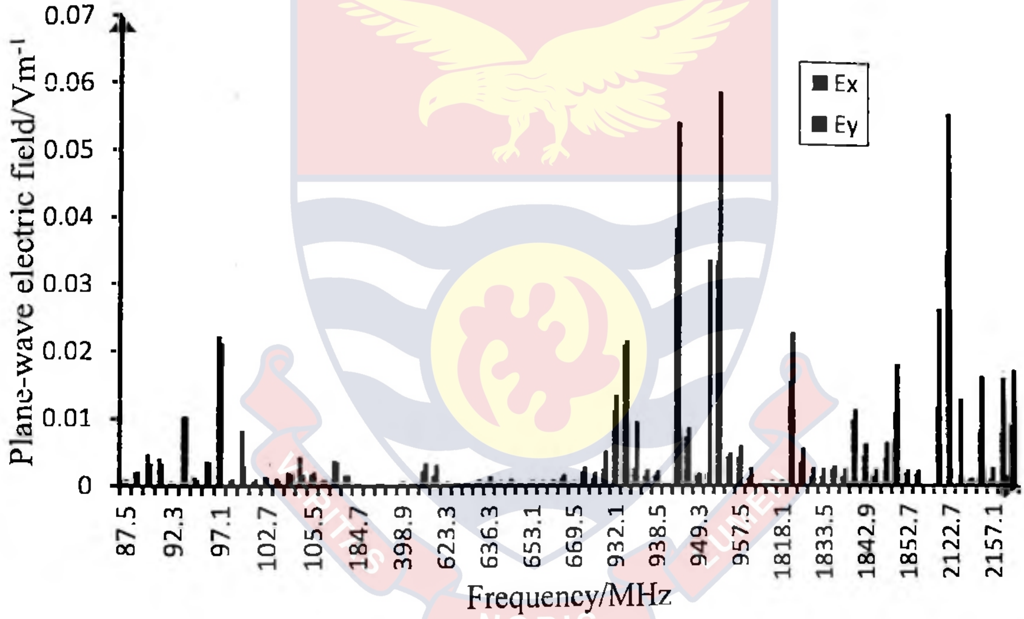

Figure 83: Variation of Electric Field Strength with Antenna Element Orientations at 1.0 m at Takoradi Harbour

The difference between the field values obtained in the two planes at the same frequency and spatial height was 0.02658 ± 0.00383 Vm^{-1}. This value was higher than the highest field strength level obtained for FM radio emissions at the same height

Time-averaged plane-wave electric field strengths at the four spatial heights were plotted in Figure 84 against their corresponding frequencies for the entire spectrum from 87.5 MHz to 2.6 GHz. The predominantly higher

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fields were observed at UHF frequencies at this spatial height. The highest field strength at 1.7 m above ground was 0.09625 ± 0.01387 Vm^{-1} from 943.9 MHz. The highest field at 1.5 m above ground also occurred at 943.9 MHz with a value of 0.09257 Vm^{-1}.

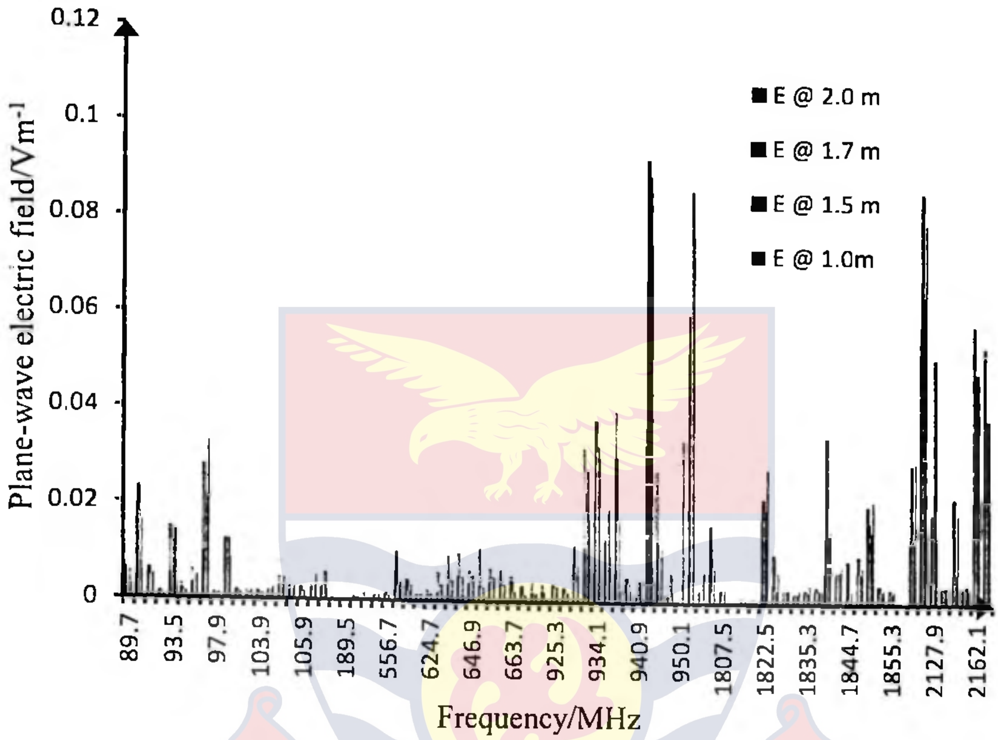

Figure 84: A Plot of Time-averaged E-fields at 1.0 m, 1.5 m, 1.7 m, and 2.0 m at Takoradi Harbour

In a plot of the spatial averaged plane-wave electric field strength for this location against frequencies producing the former as shown in Figure 85, the first two highest field strengths of 0.1674 ± 0.0241 Vm^{-1} and 0.1561 ± 0.0225 Vm^{-1} occurred at 952.5 MHz and 943.9 MHz respectively. Plane-wave electric contributions from FM radio transmissions were relatively low at this location. The highest field produced at this site by an FM radio frequency was 0.0492 ± 0.0071 Vm^{-1} at 97.1 MHz. This value is about 29.4 % of the highest field calculated for a frequency at this location.

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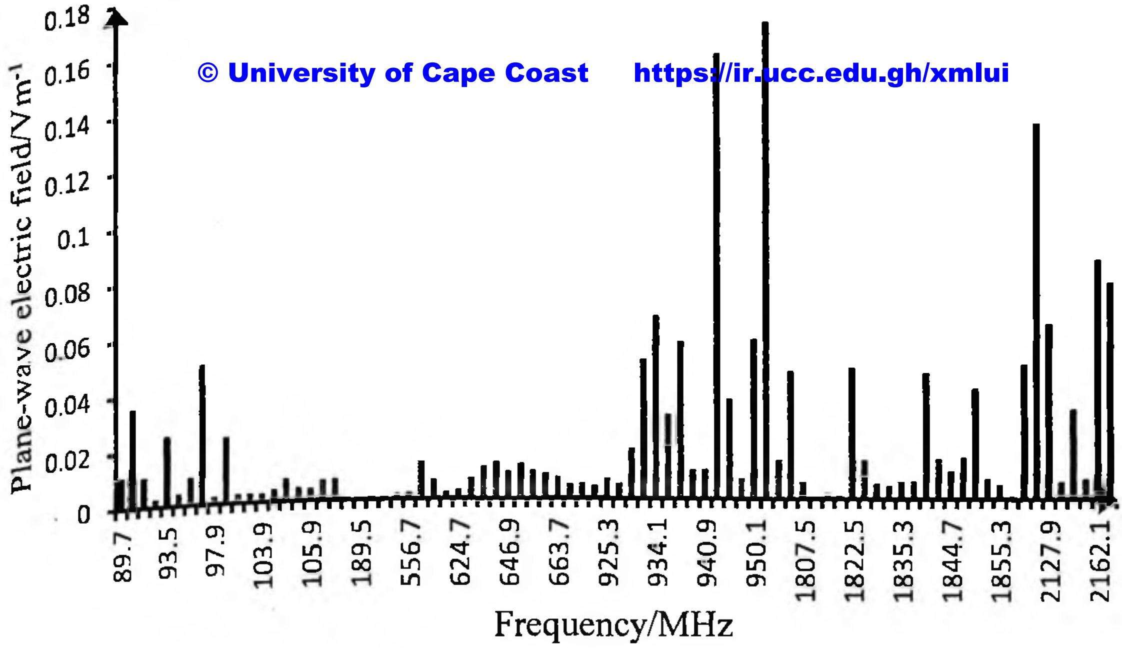

Figure 85: A Plot of E (spatial average) against Frequency for Takoradi Harbour.

In Table A34 (in Appendix A). numerical results of frequency bands analysis are summarised. The minimum plane-wave frequency-band electric field was 2.99 ± 0.43 mV/m at 1.0 m above the ground within the VHF TV band. This minimum field produced the minimum power density of 0.021 ± 0.003 μW/m². GSM 900 band contributed significant levels of electric field at this location and equally produced the maximum frequency-band electric field at a spatial height of 1.7 m. The value of the field was 178.32 ± 25.71 mVm with an associated power density of 84.34 ± 12.16 μW/m². The total exposure quotient at this location was 2.47E-05 ± 3.56E-06. Takoradi Harbour location complied with the recommended ICNIRP levels.

Market Circle

Analysis of measurements from this location shows that very low field strength is present at frequencies between 97.1 MHz and 926.5 MHz. The higher field levels at this location were due to sources operating within the

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UHF band as well as from some FM radio transmissions. There was significant variation between the field levels obtained with the antenna elements aligned with the vertical and horizontal planes. The detailed plot of how these fields varied at a spatial height of 1.0 m was plotted in Figure 86.

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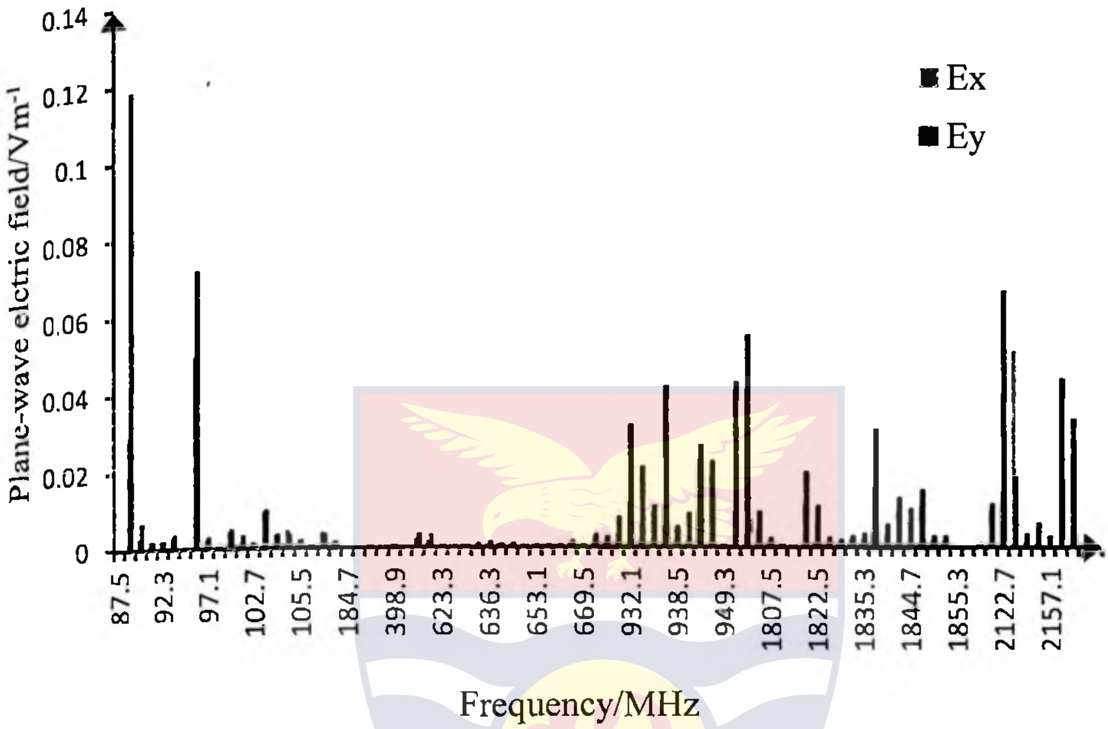

Figure 86: Variation of Electric Field Strength with Antenna Element Orientations at 1.0 m at Market Circle

The highest field strength came from 89.7 MHz FM radio. The field value with antenna elements aligned with the vertical plane was 0.1182 ± 1.69E-02 Vm^{-1}. There were relative high field strengths at 96.3, 952.5 and 2122.7 MHz. The time-average plane-wave electric field strength distributions at the four spatial heights were plotted in Figure 87. The highest plane-wave electric field strength at this location was determined at 1.5 m above ground with a value of 0.2378 ± 0.03401 Vm^{-1} at 89.7 MHz. About 47 % of the detected sources produced their highest time-averaged plane-wave electric fields at 1.7 m above ground level. Fields from FM radio transmissions were predominantly high at this location.

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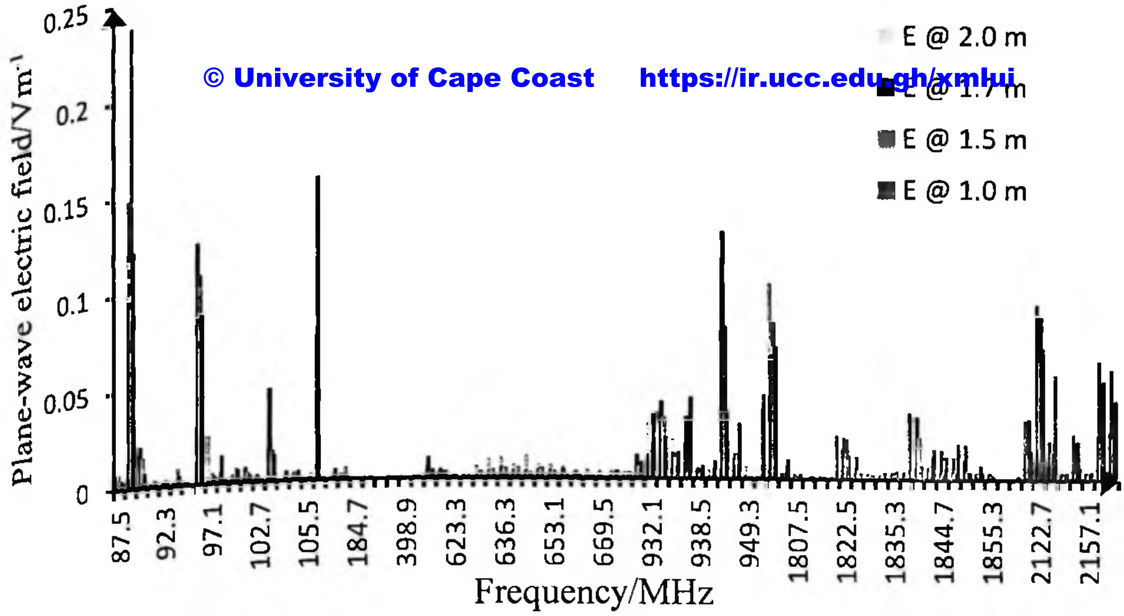

Figure 87: A Plot of Time-averaged E-fields at 1.0 m, 1.5 m, 1.7 m, and 2.0 m at Market Circle.

The spatial-averaged plane-wave electric field levels for the four spatial heights were plotted against frequency in Figure 88. The highest plane-wave field per frequency to which someone is likely to be exposed to at this location was determined to be 0.322 ± 0.046 Vm^{-1} at a frequency of 89.7 MHz. Generally, the field levels were relatively low and fairly distributed within the entire spectrum investigated. A total of 83 RF sources were detected at this location.

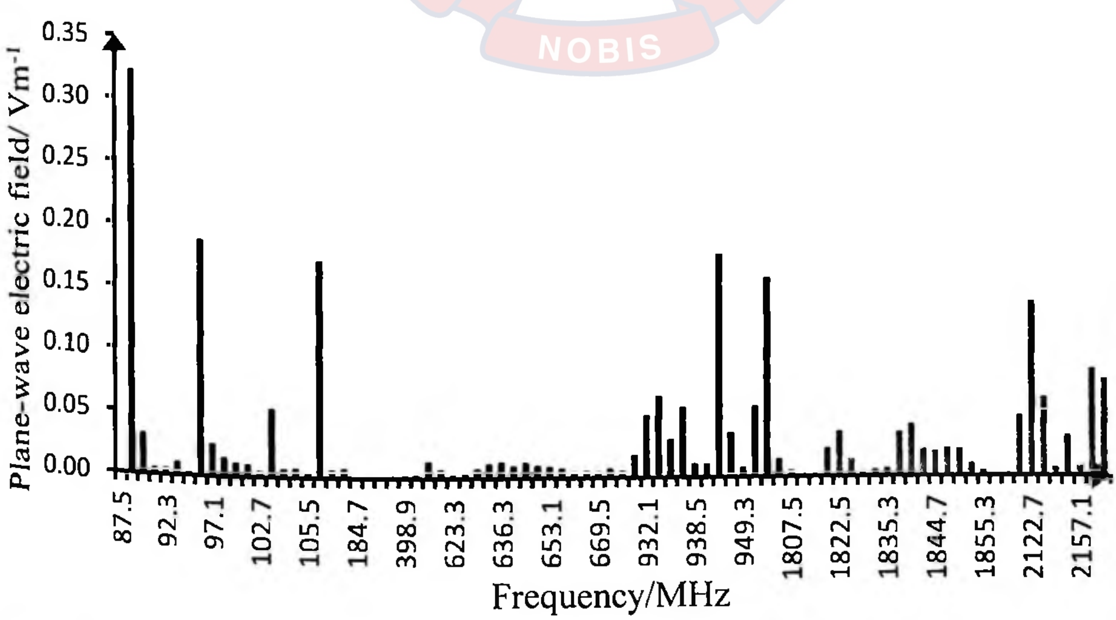

Figure 88: A plot of E (spatial average) against Frequency for Market Circle.

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Table A35 (in Appendix A) shows a summary of the numerical results for frequency groupings at this location. Spatial average field contributions from the VHF TV are the lowest at this location. The minimum value was 10.50 ± 1.50 Vm^{-1} at a spatial height of 1.7 m above ground. This electric field level produced the lowest power density of 0.29 ± 0.04 μWm^{-2}. At 1.5 m above ground, within the FM broadcast band, the maximum frequency-band spatial average electric field was 262.14 ± 37.49 Vm^{-1} with an associated power density of 182.27 ± 26.07 μWm^{-2}. The total exposure quotient for this location was 7.66E-05± 1.09E-05. The location complied with the ICNIRP recommended levels.

DuPaul

Results show that the electric field distribution at this point of interest exhibited a general variation with antenna element orientations. Relatively high values were obtained for antenna orientations that aligned antenna elements in the vertical plane in 98 % of the cases. A plot of the variations of the field strength with antenna orientations at 1.0 m above ground was plotted in Figure 89. The highest electric field strength recorded at this height was 0.043 ± 0.006 Vm^{-1} at 943.9 MHz. However, the difference in value of the plane-wave electric fields measured in the vertical and the horizontal planes was 0.0027 ± 0.0003 Vm^{-1}. The Time-averaged electric field strengths at the four spatial heights as plotted in Figure 90 against their corresponding frequencies showed that electric distribution at all the spatial heights were relatively low.

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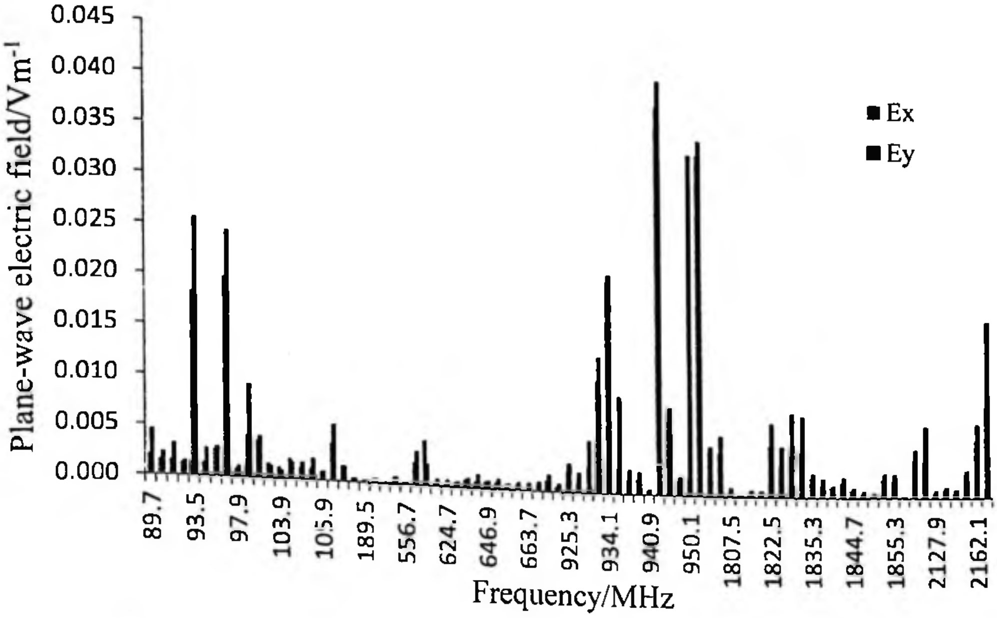

Figure 89: Variation of Electric Field Strength with Antenna Element Orientations at 1.0 m at the DuPaul location.

The maximum field strength of 0.0479 ± 0.0068 Vm^{-1} was determined at 943.9 MHz. The relatively high field strength was distributed across the entire spectrum. A contribution from the UHF band was relatively high at this location. In Figure 91, the spatially averaged plane-wave electric field levels

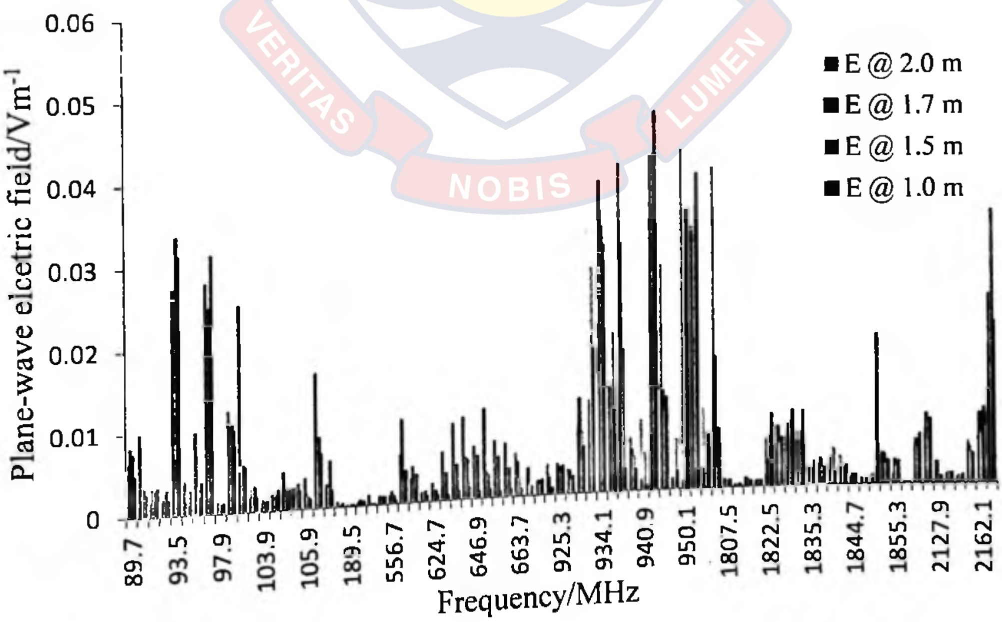

Figure 90: A Plot of Time-averaged E-fields at 1.0 m, 1.5 m, 1.7 m, and 2.0 m at DuPaul.

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were plotted against their corresponding frequencies. The maximum plane-wave electric field for this location was 0.1036 ± 0.0146 Vm^{-1} at 943.9 with an associated power density of 28.42 ± 4.01 Wm^{-2}. A total of 83 RF sources contributed to the field level at this location. Each of the electric fields due to a particular frequency is compliant with ICNIRP levels for general public exposure.

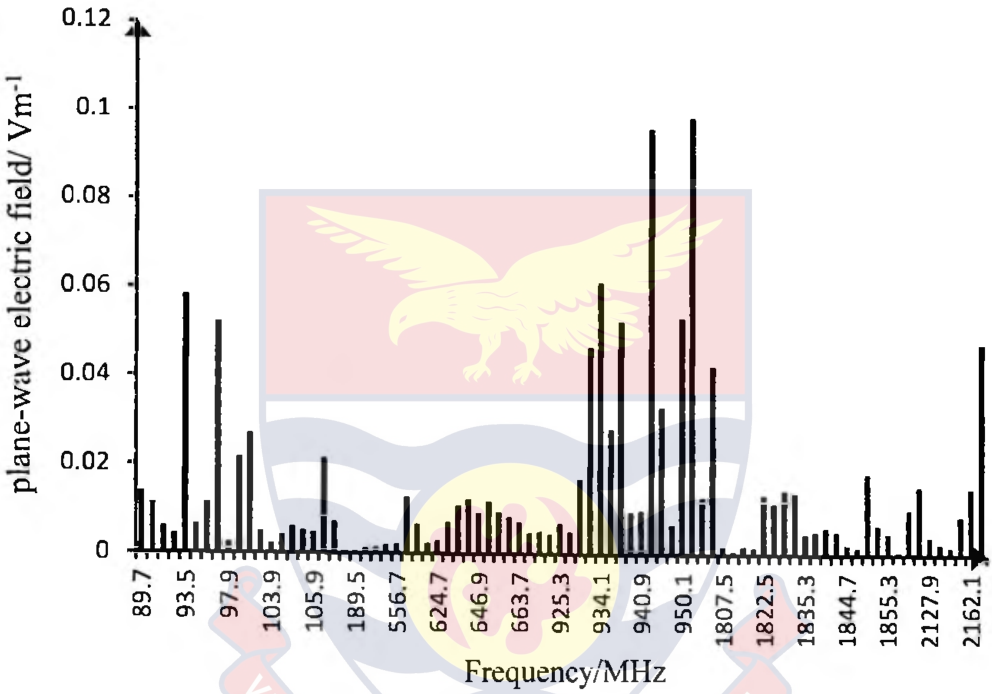

Figure 91: A Plot of E (spatial average) against Frequency for DuPaul site.

In Table A36 (in appendix A), a summary of the numerical results for DuPaul is shown for the frequency bands investigated. The highest plane-wave electric field levels were obtained within the GSM 900 band. The fields at this location were largely high compared with values from other locations within the sample size. The highest frequency band electric field strength was estimated at 1.7 m as 178.32 ± 25.14 mVm^{-1} within the GSM 900 band with an equivalent power density of 84.34 ± 11.89 $\mu W/m^2$. The site complied with the recommended ICNIRP reference levels for public exposure for each

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frequency band. The total exposure quotient for this location was 2.91E-05 ± 4.09E-06, about 0.003% of the ICNIRP recommended limit of unity. Exposure at this location complied with ICNIRP levels for public exposure.

Frequency-band Spatial Averaged Electric Field Strengths

Comparing the spatial average plane-wave electric fields from within the FM bands at the 30 locations (Figure 92), only 20% have electric field levels above 200 mVm^{-1}. The maximum spatial average electric field from FM band occurred at Manhyia location. The value was 1181.82 ± 166.61 mVm^{-1} with a corresponding power density of 0.0037 ± 0.0005 Wm^{-2}.

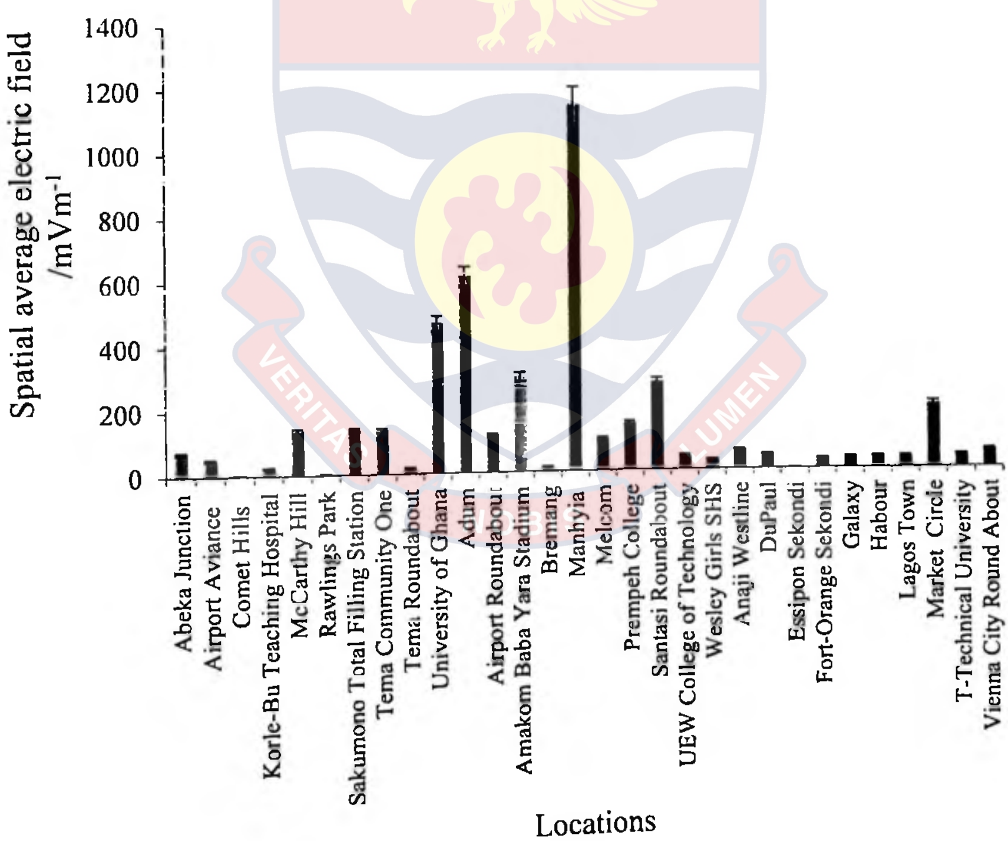

Figure 92: A Plot of Spatial Average Electric Fields for FM Broadcast Bands

The exposure quotient for this field level was 1.32E-04 ± 1.87E-05. Even though this level about 4.22% of the ICNIRP recommended limit of 28

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Vm^{-1}, it is relatively higher than levels from other locations. The difference between this level and the next highest level was 554.7 mVm^{-1} representing 46.9% increase. Four out of the six locations that recorded electric field levels above 200 mV/m are located in Kumasi. The maximum value for Accra-Tema and Sekondi-Takoradi was 476.81 ± 68.23 mVm^{-1} and 208.0 ± 29.74 mVm^{-1}, respectively. University of Ghana recorded the maximum field for Accra-Tema whilst Market Circle location had the maximum for Sekondi-Takoradi.

Rawlings Park and Comet Hills in Accra-Tema and Essipong Sekondi recorded the minimum spatial average electric field levels of 3.14 ± 0.45 mVm^{-1}, 3.45 ± 0.48 mVm^{-1} and 3.7 ± 0.5 mVm^{-1} respectively. These field levels are less than 0.5% of the maximum electric field strength within the FM broadcast bands from other locations. Coincidentally these two locations are heavily populated market areas. The human body is more susceptible to FM frequency radiations than to higher frequencies. These low levels of the FM broadcast band electric fields at these locations are as a result of shielding by the high rising buildings which surround the two locations.

The results from the FM broadcast band are found to be largely elevated compared with published work by Azah et al. (2013). The maximum and the minimum spatial average plane-wave electric field values from this study were, respectively, about 21.89 and 45,945.95 times higher than the findings from Azah et al. (2013). Compared with a recent publication by Deatanyah, Abavare, Menyeh, and Amoako (2018), the field levels in this work are of similar magnitude as those reported by Deatanyah et al. (2018). The maximum and minimum field levels reported in their publication was respectively, 1220 ± 100 mV/m and 12.50 ± 1.02 mV/m. This implies that

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there has been increased emission from FM radio stations since 2013. The reasons for the elevated values could also be attributed to the increase in the number of FM transmitters over the period as well as an increase in power levels that feed the antennas.

In Figure 93, the VHF TV band electric field strengths are relatively high in Kumasi. About 86.7% of the sample space recorded field levels far below 100 mVm^{-1}. The four locations that had VHF TV band electric fields in excess of 100 mVm^{-1} were all located in Kumasi. The maximum spatial average electric field from within the VHF TV band was determined at Amakom Baba Yara Stadium location. The value of the field strength was 458.25 ± 65.91 mVm^{-1} with a corresponding power density of 557.01 ± 80.21 μWm^{-2}. The least VHF TV band spatial average electric field was estimated at Rawlings Park in Accra-Tema. The value was 0.98 ± 0.14 mVm^{-1} representing about 0.2% of the maximum spatial field within this band. Other locations with very low exposure to VHF TV band electric fields were Vienna City Roundabout with 0.98 ± 0.14 mVm^{-1} and Galaxy Aben Be Bong with 2.65 ± 0.37 mVm^{-1} respectively. Generally exposure to VHF TV band electric fields is low.

The maximum and the minimum electric fields from this work are, respectively, about 127.66 times lower than the levels reported by Osei, Amoako, and Fletcher (2016). Osei et al. (2016) conducted their survey in the near-field of the transmitting antennas.

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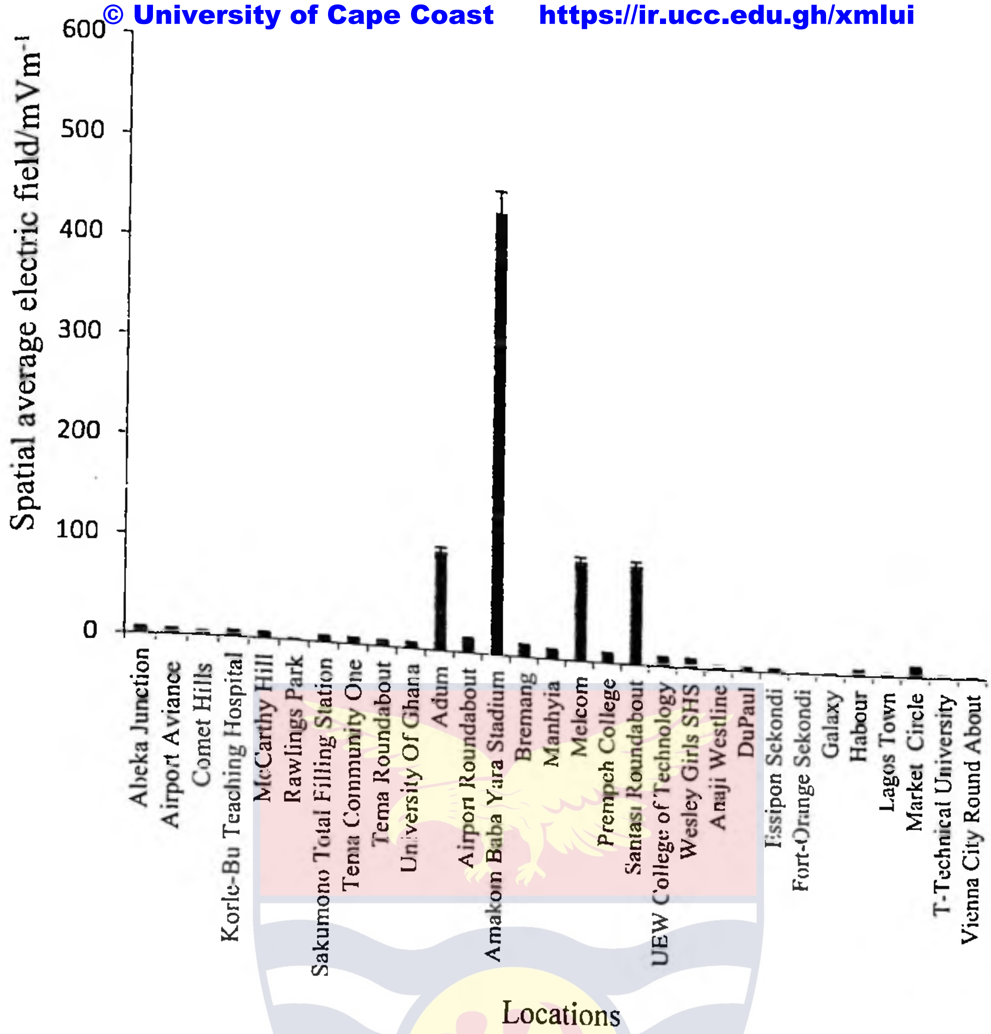

Figure 93: A Plot of Spatial Average Electric Field Levels for VHF TV Band

Exposure to UHF band electric fields (Figure 94) was below 200 mVm^{-1} at all the 30 locations. However, some locations were estimated to have elevated levels than the mean value of 66.17 mVm^{-1}. 12 locations representing 40% of the sample space had estimated spatial average electric fields above the mean value. The maximum field level was estimated at Manhyia location in Kumasi with a value of 194.69 ± 27.45 mVm^{-1}. The least field was determined at Comet Hills in Accra-Tema and had magnitudes of 1.70 ± 0.24 mVm^{-1}

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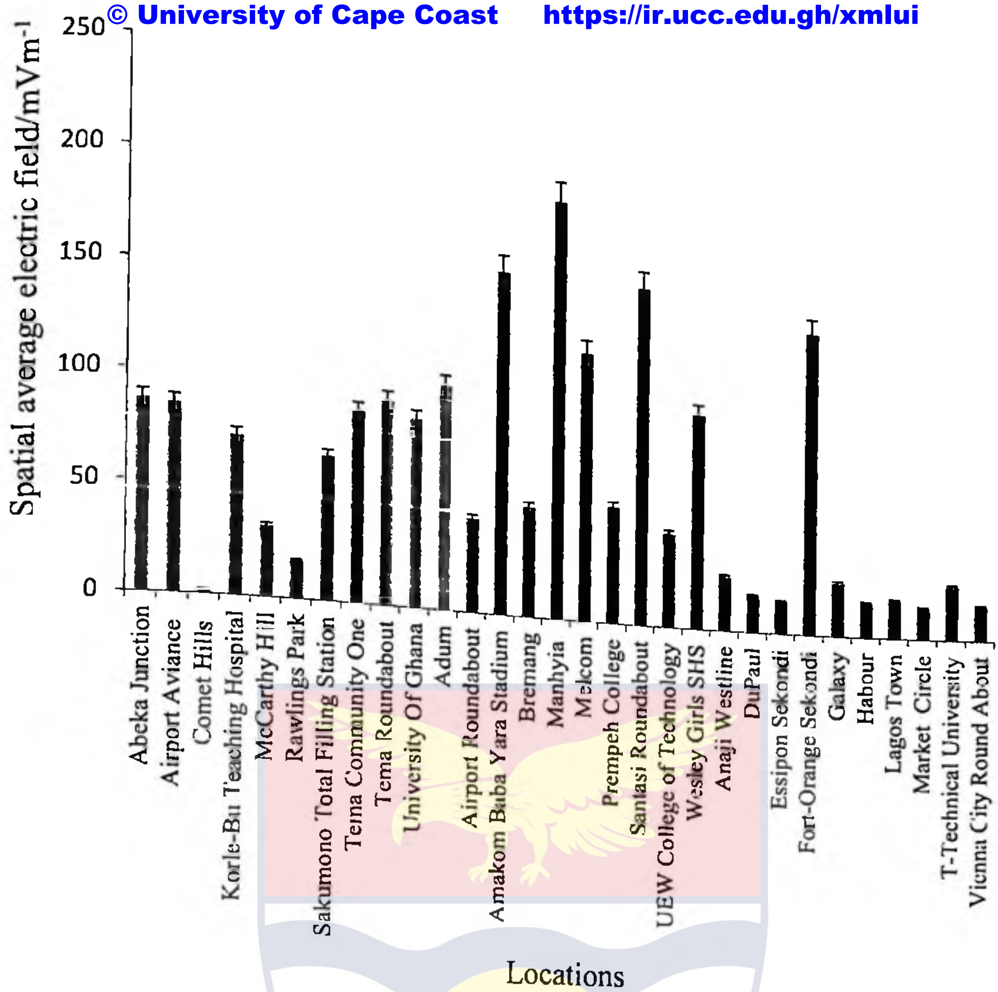

Figure 94: A Plot of Spatial Average Electric Field for UHF TV Band

GSM 900 frequency band field distribution in Accra-Tema is higher than in the Kumasi and Sekondi-Takoradi (Figure 95). The mean spatial average field distribution was 237.17 mVm^{-1}. Eleven locations recorded values above this mean field strength. The highest four values were determined for locations in Accra-Tema. Tema Community One and University of Ghana recorded the maximum spatial average electric fields of 651.4 ± 93.2 mVm^{-1} and 638.1 ± 91.5 mVm^{-1} respectively. The minimum spatial average field within this band was determined at Comet Hills in Accra with a value of 5.91 ± 0.83 mVm^{-1}. This work compares favourably to Amoako, Fletcher, and Darko, (2009). The highest power density within this

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band according to this work was 1.125 ± 0.16 mWm^{-2}. This value was 112.5 times higher than the maximum level reported by Amoako, Fletcher, & Darko, (2009) within the same frequency band. The variations indicate that GSM 900 electric fields have increased since 2009. More BTS have been added to accommodate the ever increasing subscriber base in Ghana.

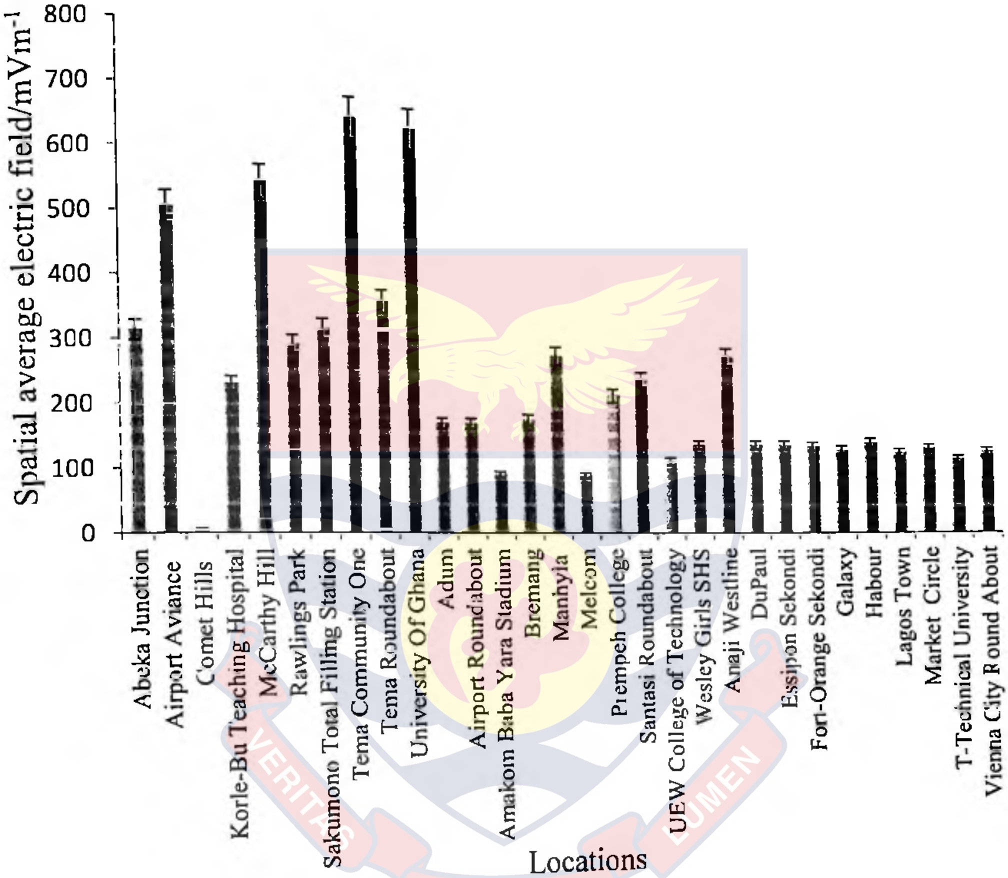

Figure 95: A plot of Spatial Average Electric Field for GSM 900 Band

GSM 1800 band fields have elevated levels in Accra-Tema than at other locations within the sample space. The maximum spatial average electric field was determined at Tema Round About with an estimated value of 320.9 ± 51.4 mVm^{-1}. A total of 14 locations registered levels above the mean electric field level of 146.37 mVm^{-1}. Nine out of ten locations in Accra-Tema had spatial field above this mean. The mean spatial average electric field is about

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45.6% of the maximum field within the sample space. Figure 96 shows how the fields are distributed within the sample space.

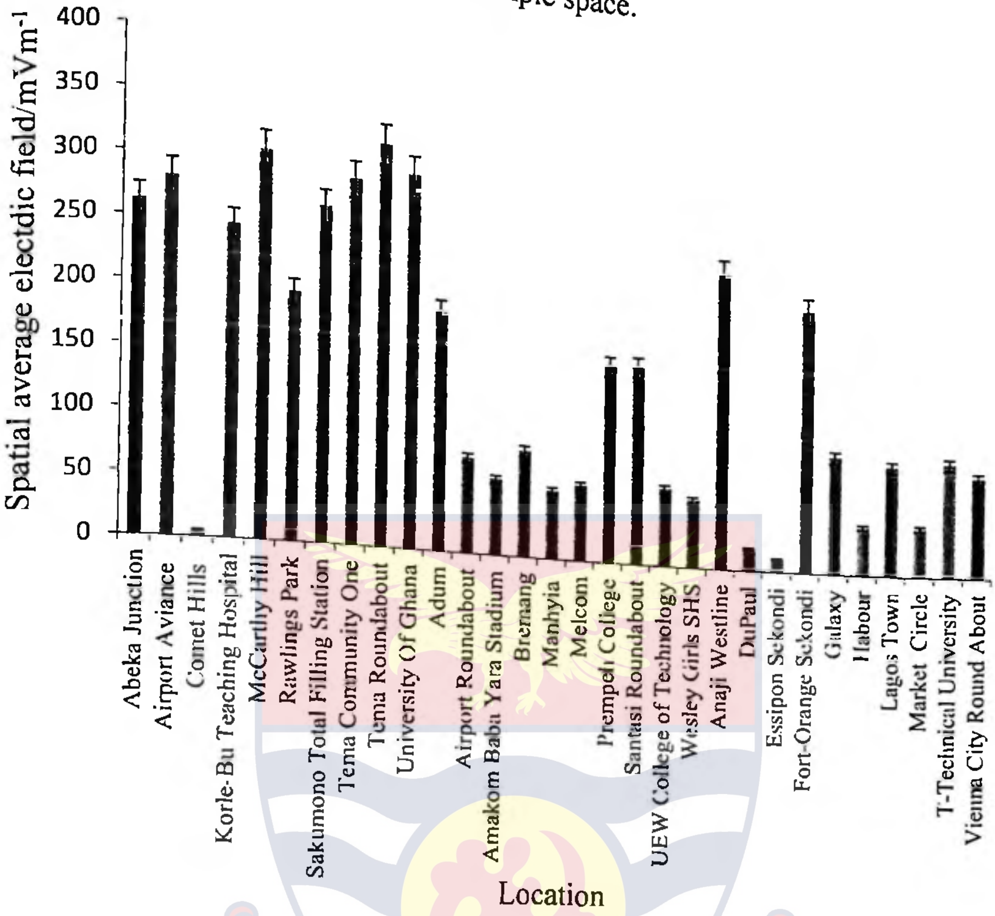

Figure 96: A Plot of Spatial Average Electric Field for GSM 1800 Band

Comet Hills in Accra-Tema had the minimum spatial average electric field of 5.08 ± 0.71 mVm^{-1}. DuPaul and Essipon Sekondi locations also had very low spatial average electric fields of magnitude 18.46 ± 2.60 mVm^{-1} and 11.34 ± 1.60 mVm^{-1}. Three locations in Kumasi had spatial field levels above the mean spatial electric field value of the sample space. Anaji West Line and Fort Orange Sekondi are the only locations with field strength values above the mean spatial average electric field. The maximum power density reported for this band was 0.273 ± 0.039 mWm^{-2}. This value is 2.73 times higher than the maximum field strength reported by Amoako et al (2009). In a survey by Deatanyah et al (2012) who assessed various BTS at different location, the

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maximum power density reported by them was 1.19 mWm^{-2} which is 4.36 times higher than the values reported in this work.

The mean spatial average electric field strength within the UMTS (WCDMA/3G) was 219.531 mVm^{-1}. Eight locations had spatial average electric field strengths above this mean value. The maximum spatial average electric field strength was determined at University of Ghana to be 892.44 ± 127.62 mVm^{-1}. The next highest field was 790.65 ± 113.06 mVm^{-1} at Tema Community One location (Figure 97).

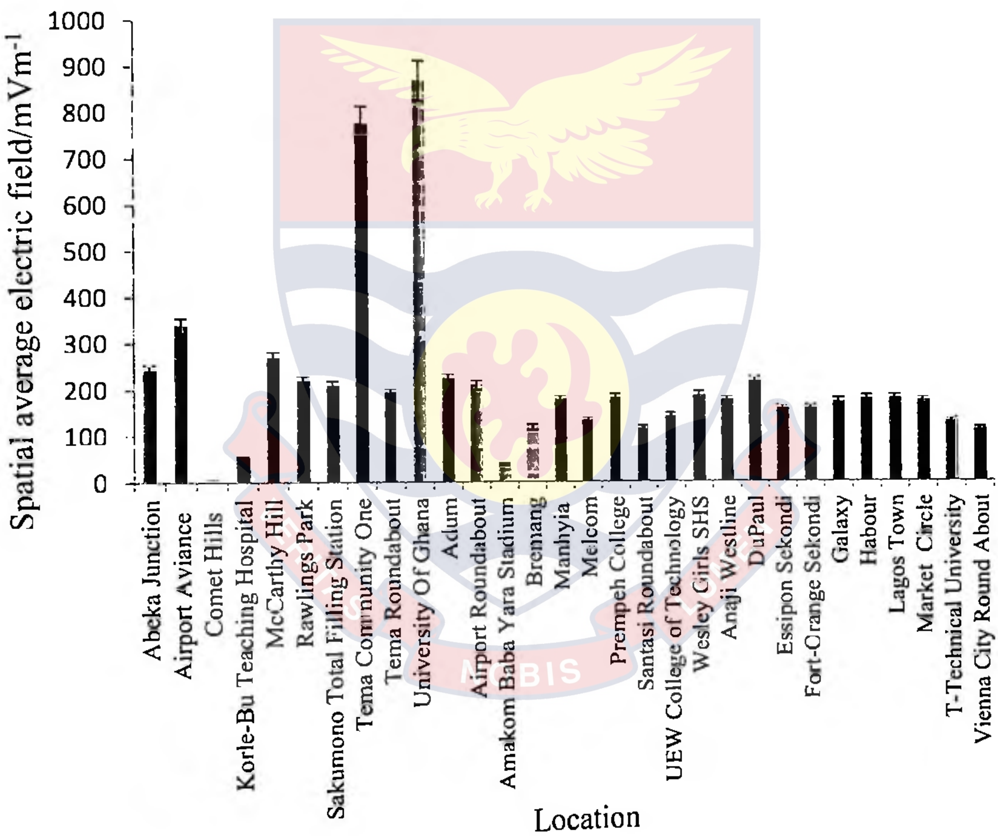

Figure 97: A Plot of Spatial Average Electric Field for UMTS Band

Comet Hills location produced the minimum spatial average electric field. The value was 5.24 ± 0.73 mVm^{-1}. This value is about 27.9 times below the mean spatial average field for this band. In general, the exposure of the members of the general public to UMTS (WCDMA/3G) band fields at the

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locations investigated are well below the ICNIRP recommended limit. Table A37 (in Appendix A) shows the spatial average plane-wave electric field strengths at all locations investigated in this work. Figure 98 summarises the nature and level of all the electric fields present at measurement sites in Accra-Tema study area. University of Ghana had the highest levels of electric field followed by Tema community One. Comet Hills had the lowest field levels. This implies that the inhabitants of UG are exposed to more RF radiations than elsewhere within Accra-Tema study areas

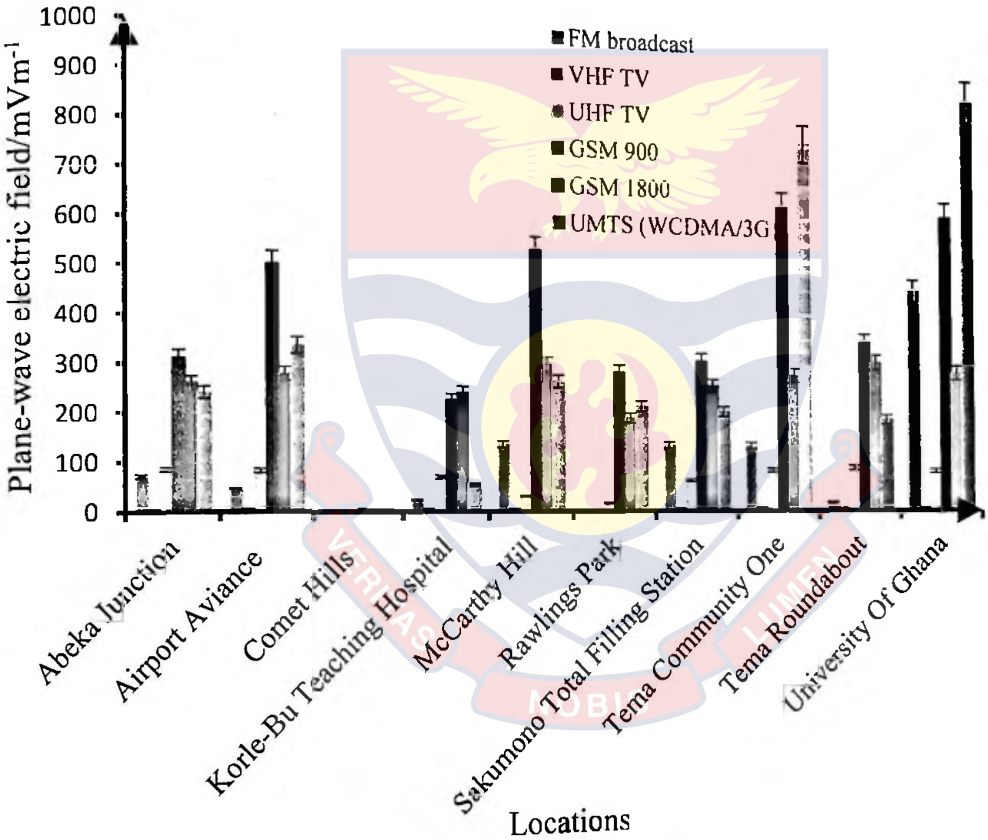

Figure 98: Electric Field Strength at Accra-Tema Sites Compared.

In Figure 99, electric field strength distributions at the Kumasi study area were plotted. Manhyia and Adum study areas have relatively elevated electric field strengths from FM broadcast band. Contributions to electric field strength from other service bands rank in the same order as those recorded in Accra-Tema and Sekondi-Takoradi study areas.

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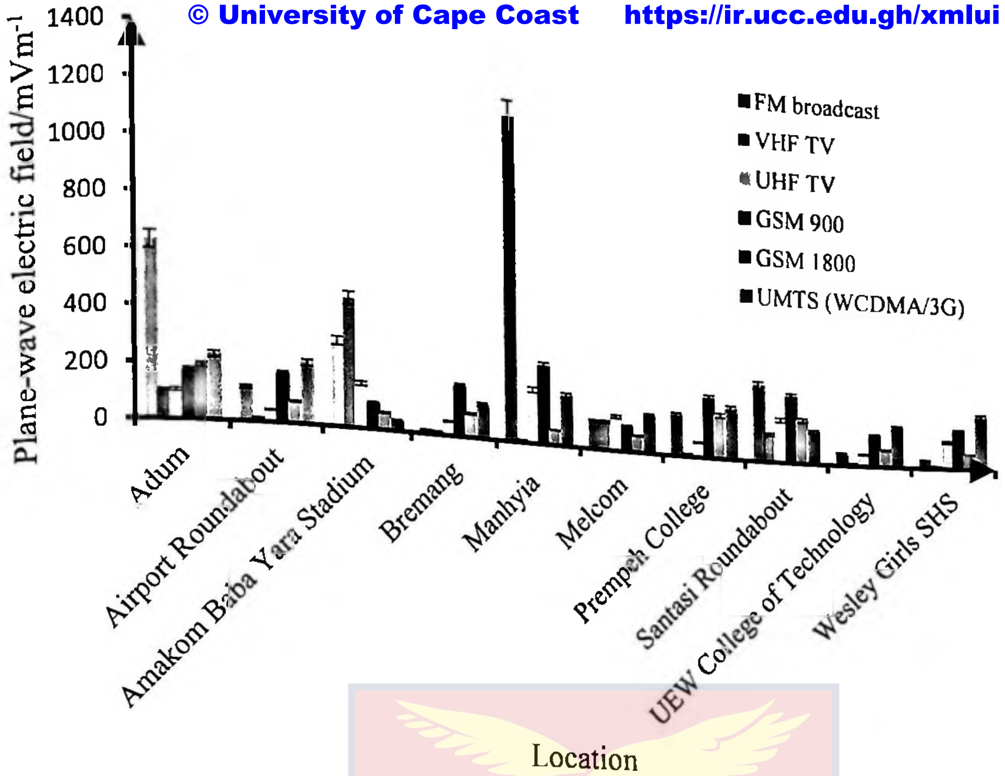

Figure 99: Electric Field strength at Kumasi Sites Compared.

Electric field strength from GSM 900 service band had a consistent magnitude at all study sites within Sekondi-Takoradi (Figure 100). However exposure at Anaji Westline and Fort Orange study areas were the highest.

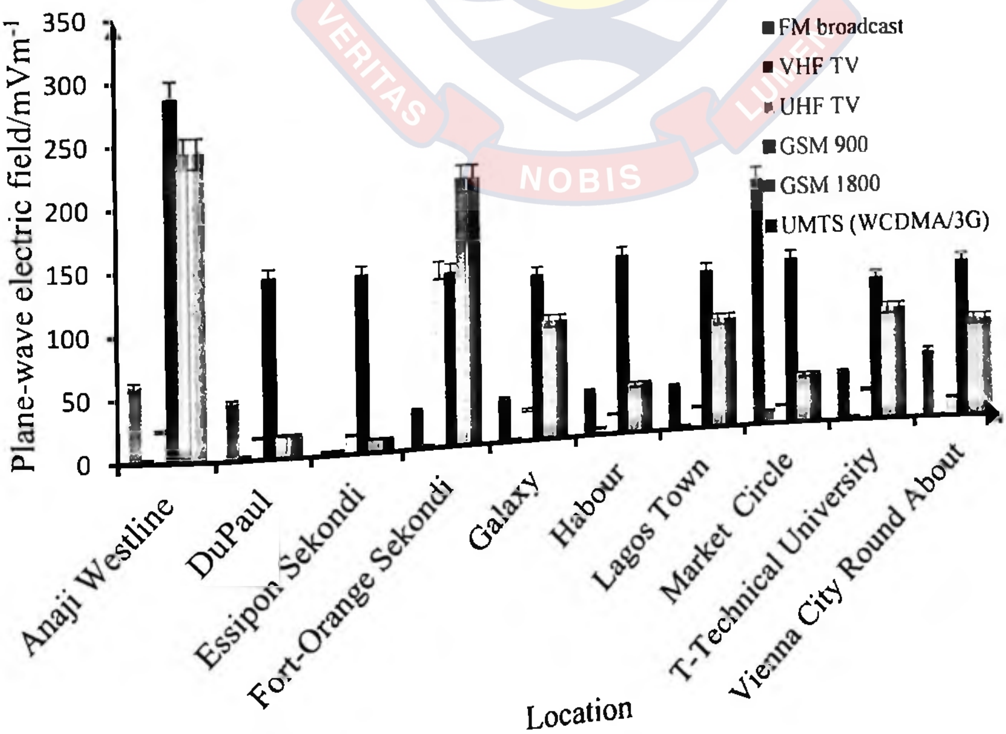

Figure 100: Electric Field Strength at Sekondi-Takoradi Sites Compared.

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Estimation of SAR and RF Energy Produced in Biological Tissues

An approximate calculation method was employed to determine energy absorption by biological tissues. This calculation scheme considered the penetration of a plane-wave RF electric field, propagating in one direction i.e. propagating from left to right, and incident normally on an air-tissue interface. Using dielectric properties of body tissues at RF and Microwave frequencies compiled by Gabriel (1996) and a set of equations; equations 3 to 12, the permittivity, conductivity, skin depth and the impedance of skin (dry and wet) and the eye (sclera and cornea) were calculated. The results were checked against values supplied in the FCC tissue dielectric properties calculator at http://www.fcc.gov/fcc-bin/dielec.sh. In Figure 101, a plot was made of the variation of the calculated impedance with the frequencies investigated for dry skin, wet skin, sclera, and the cornea.

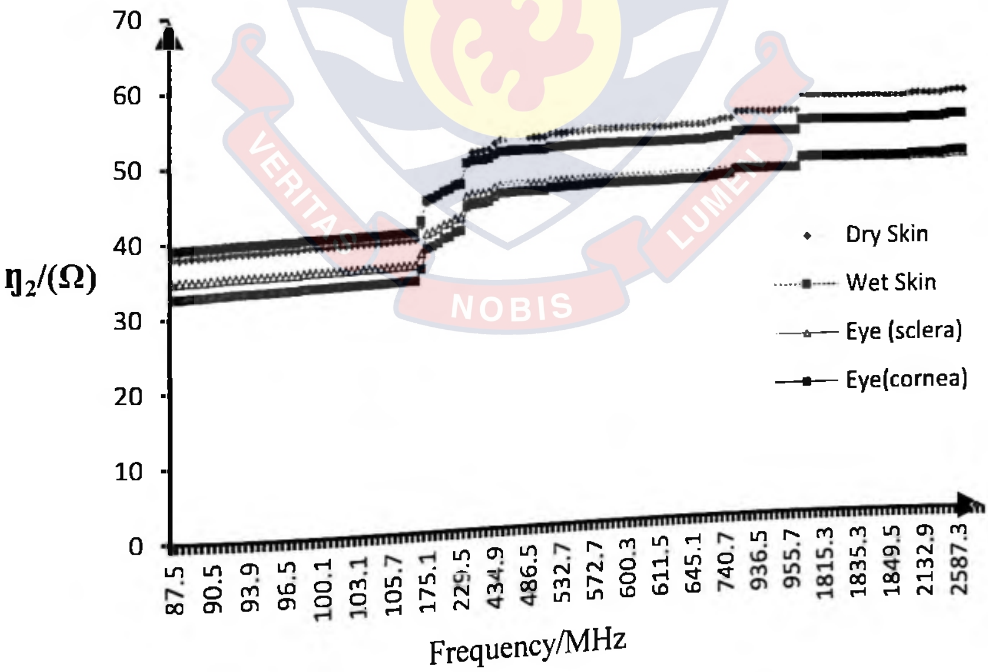

Figure 101: Variation of Impedance of Selected Tissues with Frequencies

At FM frequencies, the lens cortex exhibited the highest impedance to RF fields and the cornea of the eye had the least impedance. The variations of

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the impedances of the four tissues were marginal within the FM range. There was a sharp increase in the impedance values within the VHF TV band. Within the UHF TV band and beyond, the impedance of the dry skin increased rapidly and had the highest values with the sclera and cornea of the eye exhibiting the lowest values.

In Figure 102, the skin depth; the distance a plane-wave travels within a material until it decays to 1/e of its initial amplitude, was plotted against frequency for the four tissues.

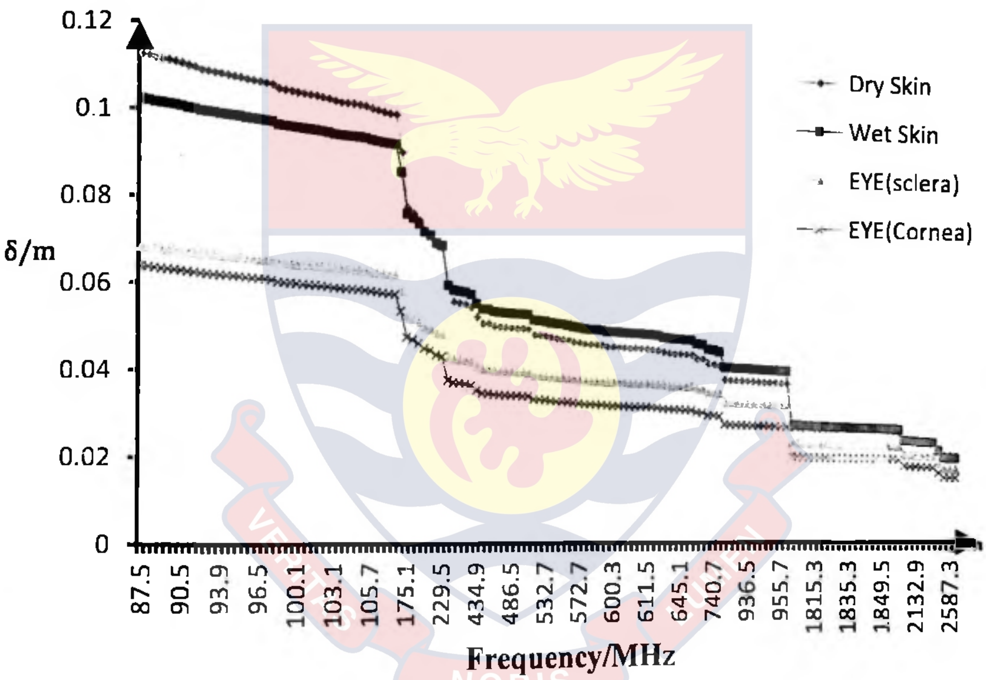

Figure 102: Variation of Skin Depth with Frequency for Selected Tissues

Within the FM band, dry skin exhibited the highest skin depth values which sharply decreased within the subsequent bands. Within the UHF TV band and beyond, skin depth values of wet skin were predominantly the highest. The cornea of the eye had consistently low skin depth values. The electrical conductivity of the tissues is plotted in Figure 103. The values did not vary much within the frequency bands investigated. For all the tissues, the

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conductivity increased with increasing frequency. The cornea of the eye is the highly conductive of the four tissues.

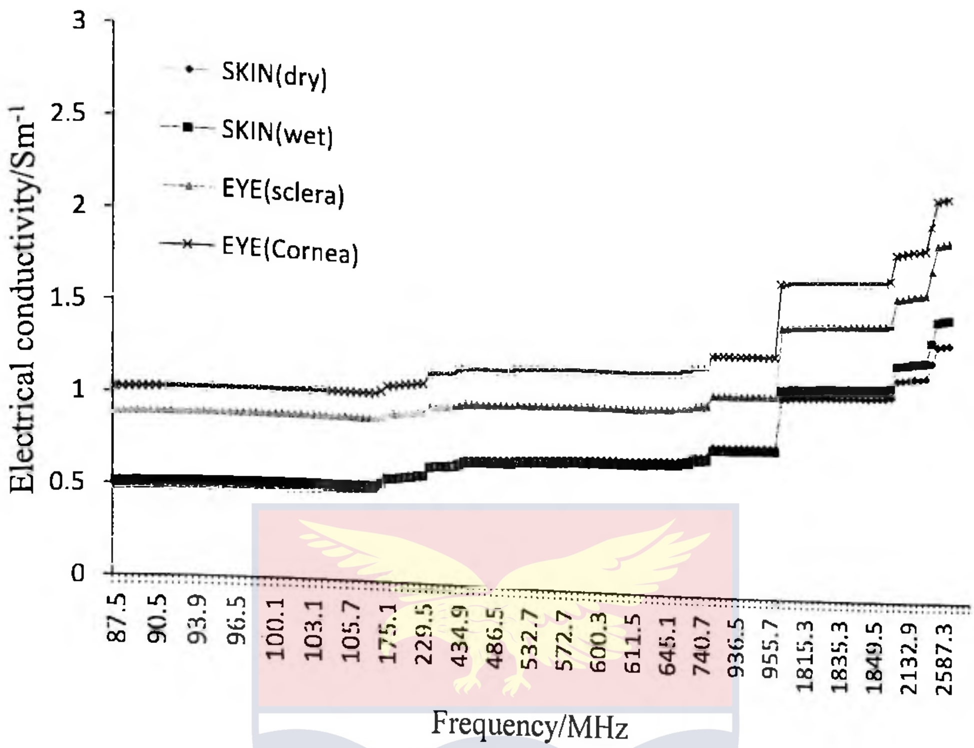

Figure 103: Variation of Electrical Conductivity with Frequency for Selected Tissue

The plane-wave electric fields transmitted through the air-tissue boundaries into the four tissues were estimated using the impedance values in Table A38 (in Appendix A) and the calculated transmission coefficients found in Table A39 (in Appendix A). In Table A40 (in Appendix A) and Table A41 (in Appendix A), the calculated electrical conductivity and permittivity of the tissues of concern were displayed. Equation 75 was employed to calculate the transmission coefficients. The estimated spatial average plane-wave electric field strength transmitted into dry skin, wet skin, the sclera of the eye and the cornea of the eye are shown in Table A42, Table A43, Table A44 and Table A45 respectively (in appendix A).

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Levels of transmitted electric field into wet skin were greater than the

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levels induced in other tissues. This implies that persons who are wet and find themselves in these fields will get higher exposure than those with dry skin. The dry skin also had transmitted electric field levels higher than the sclera and cornea of the eye. Results indicate that wet skin allows in 2.28% more plane-wave electric field than dry skin, 9.93% more than the sclera and 14% than the cornea. Using FM broadcast data from Manhyia location in Table A14; ambient spatial average electric field strength of 1.1818 V/m resulted in an estimated transmitted electric field of 0.2276 ± 0.0321 Vm^{-1} into wet skin, 0.2224 ± 0.0314 Vm^{-1} into dry skin, 0.2050 ± 0.0289 Vm^{-1} into sclera and 0.1939 ± 0.0273 Vm^{-1} into the cornea of the eye. The sclera of the eye also had 5.41% more transmitted electric field than into the cornea of the eye.

SAR values were calculated for the four tissues employing equation 1. The transmitted plane-wave electric field strength values for the respective tissues were used in the estimation of their SAR values.

Sclera SAR Values

Olsen, Aaberg, Geroski, and Edelhauser1 (1998) in a bid to assess the mean thickness and surface area of human sclera, hemisected 25 formalin-fixed eye bank eyes from anterior to posterior. The total scleral surface area was determined by either a computerized tracing method (17 globes) or volumetric calculations (eight globes) using fluid displacement. Olsen et al. (1998) published the mean total scleral surface area as 16.3 ± 1.8 cm^2 and 17.0 ± 1.5 cm^2 for surface area computerized tracings and volume displacement method respectively. This work used 16.65 ± 1.65 cm^2; the mean value of the

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two results. In a paper written by Thijssen, Mol, & Timmer, (1985) the density

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of the sclera was calculated from two ocular properties given; sound wave velocity and characteristic impedance. The density was estimated using $\eta_o = \rho . c$ with η_o as the characteristic impedance of a medium, ρ as the density and c as the speed of sound. The calculated density of the sclera is 1.029 g/cm^3 or 1029 kg/m^3. These values were employed in the estimating of the SAR values.

The highest SAR value for electric fields from within the FM broadcast band (Table A46 in Appendix A) was 36.9 ± 5.20 μWkg^{-1}. This SAR value is associated with exposure at Manhyia location. The location with the least SAR due to electric field from FM broadcast bands was Comet Hills with a value of 0.00593 ± 0.00083 μWkg^{-1}. From within the VHF TV band, the sclera had the maximum estimated SAR of 7.76 ± 1.12 μWkg^{-1} whilst the minimum value of 0.0000366 ± 0.00000521 μWKg^{-1} was associated with the Rawlings Park location. Manhyia location's maximum SAR for UHF TV, GSM 900, GSM 1800 and UMTS (WCDMA) bands were 2.02 ± 0.29 μWkg^{-1}, 26.63 ± 3.78 μWkg^{-1}, 9.23 ± 1.30 μWkg^{-1} and 80.84 ±11.64 μWkg^{-1} respectively.

Cornea SAR Values

The macroscopic anterior surface area of the human cornea as calculated by Kwok (1984) for three models of the average human cornea was used. In his calculations, Kwok used a general ellipsoid model, a spherical model and a rotational ellipse model (rotationally symmetric ellipsoid). The general ellipsoid model and the rotational ellipse gave a surface area of 132

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mm², while the spherical model gave 126 mm². This work used 130 mm²
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which is an average of the three values. From Thijssen, Mol & Timmer (1985), the density of the cornea was calculated as 1.024 g/cm³.

The SAR values obtained for the cornea of the human eye at this location ranged from a maximum of 36.93 ± 5.20 μWkg⁻¹ at Manhyia within the FM broadcast band to a minimum of 1.76E-05 ± 2.46E-06 μWkg⁻¹ at Comet Hills within the UMTS (WCDMA/3G) band. The Maximum SAR values within the VHF TV, UHF TV, GSM 900 and GSM 1800 bands are 7.76 ± 1.12 μWkg⁻¹, 2.02 ± 0.29 μWkg⁻¹, 26.65 ± 3.78 μWkg⁻¹ and 80.84 ± 11.62 μWkg⁻¹ respectively. The minimum SAR values estimated within the VHF TV, UHF TV, GSM 900 and GSM 1800 bands are 3.66E-05 ± 5.21E-06 μWkg⁻¹, 3.58E-03 ± 5.01E-04 μWkg⁻¹, 1.38E-05 ± 1.93E-06 μWkg⁻¹, and 2.94E-04 ± 4.12E-05 μWkg⁻¹. The detailed distribution of SAR levels for the cornea is displayed in Table A47 (in Appendix A).

Wet Skin and Dry Skin SAR Values

This work relied on data provided by Shirazu, Mensah, Schandorf and Mensah (2017). In the work, five important body indexes were measured; body height, body weight, BMI BSA and BSI using DuBois formula as the fundamental basis. Shirazu et al. (2017) reported the mean body surface area (BSA) for an average male with mean age of 45 years, weight of 80.83 kg and height of 178.62 cm as 1.69 ± 0.12 m². The work also gave the average female measurements as; mean age of 46 years, weight of 61.87 kg, height of 167.11 and BSA of 1.69 cm². The density of skin used in the calculations was 1109 kg/m³. This value was reported by Wu, Rappaport, and Collins (2015).

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Table A48 and Table A49 (all in Appendix A) show the detailed
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distribution of SAR values for dry and wet skins respectively. SAR values obtained for wet skin were slightly higher than for dry skin. This indicates that persons with wet skin absorb more energy from ambient plane-wave electric fields than those whose skins are dry. The maximum SAR values for wet skin estimated within the FM broadcast, VHF TV, UHF TV, GSM 900, GSM 1800 and UMTS (WCDMA/3G) bands were 24.34 ± 3.43 μW/kg, 5.34 ± 0.77 μW/kg, 1.54 ± 0.22 μW/kg, 21.2 ± 3.01 μW/kg, 7.88 ± 1.11 μW/kg and 69.74 ± 9.99 μW/kg respectively. The minimum SAR values within each of the frequency bands were 1.69E-04 ± 2.41E-05 μW/kg for FM broadcast band, 2.10E-05 ± 2.99E-06 μW/kg for VHF TV band, 2.40E-03 ± 3.36E-04 μW/kg for UHF TV band, 3.10E-05 ± 4.34E-06 μW/kg for GSM 900 band, 1.80E-04 ± 2.52E-05 μW/kg for GSM 1800 band and 12.72 ± 1.78 μW/kg for UMTS (WCDMA/3G) band.

The maximum SAR values for dry skin, estimated within the FM broadcast, VHF TV, UHF TV, GSM 900, GSM 1800 and UMTS (WCDMA/3G) bands were 21.8 ± 3.07 μW/kg at Manhyia, 5.29 ± 0.76 μW/kg at Baba Yara Stadium, 1.70 ± 0.24 μW/kg at Manhyia, 23.74 ± 3.37 μW/kg at Tema community One, 8.35 ± 1.18 μW/kg at Tema Roundabout and 72.53 ± 10.42 μW/kg at University of Ghana. The difference between the maximum SAR for Dry skin and wet skin at Manhyia within the FM broadcast band was 2.54 ± 0.36 μW/kg. The SAR values reported in this volume are several times lower than levels estimated by Sallomi (2012) in the head during mobile phone usage. Sallomi reported the maximum SAR in the skin, associated with

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GSM 1800 phone usage, as 0.200 W/kg and 0.1029 W/kg as the SAR in the
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skin associated with GSM 900 phones.

Estimated Transmitted Energies within Tissues

Worst-case scenario energies transmitted into human tissues have been estimated for the Sclera of the eye, the cornea of the eye, wet skin and dry skin using the right hand side of equation 76. The maximum estimated energy transmitted into the cornea as a result of its presence in the ambient fields measured was 0.112 ± 0.0158 MJ at Manhyia location within the FM broadcast band. The maximum energy values for cornea, estimated within the VHF TV, UHF TV, GSM 900, GSM 1800 and UMTS (WCDMA/3G) bands were 19.92 ± 2.87 kJ at Baba Yara stadium, 0.29 ± 0.041 kJ at Manhyia, 49.02 ± 6.96 kJ at Tema community One, 12.10 ± 1.71 kJ at Tema Roundabout and 12.13 ± 1.71 kJ at University of Ghana. The minimum energy values estimated within each of the frequency bands were 0.75 ± 0.106 J for FM broadcast band at Rawlings Park location, 0.102 ± 0.0145 J for VHF TV band, 6.44 ± 0.902 J for UHF TV band, 0.0215 ± 0.0031 J for GSM 900 band, 0.329 ± 0.0461 J for GSM 1800 band and 0.0203 ± 0.0028 J for UMTS (WCDMA/3G) band. In Table A50 (in Appendix A), the values of the estimated energies within the cornea at the various locations were displayed.

Energies estimated for the Sclera of the eye ranged from a maximum of 1.43 ± 0.20 MJ within the FM broadcast band at Manhyia location to 0.265 ± 0.0371 J within the WCDMA/3G band at Comet Hills. Table A51 (in Appendix A) shows the detailed estimated energies for the all the locations and frequency bands. The estimated energies for wet skin ranged between

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1750.10 ± 247.13 MJ at Manhyia location and 3.55 ± 0.497 kJ at Comet Hills.

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The maximum estimated energy for dry skin was 1850.23 ± 261.13 MJ whilst the minimum estimated energy was 0.195 ± 0.027 kJ. Table A52 and Table A53 (all in Appendix A) show the detailed estimated energy values for dry and wet skins respectively. The high values of the estimated energies at some locations can be attributed to the relatively high levels of ambient electric field strengths at those locations. The elevated electric field strengths were determined at locations with relatively high elevations. The highest field strength was determined at an area 287.8 m above sea level (Table A6 in Appendix A). The uncertainty associated with electric field strength measurement and the statistical analysis on electric field strength levels are shown in Table A54 and A55 (all in Appendix A) respectively.

Chapter Summary

The electric field trend at Kumasi, Accra-Tema and Sekondi-Takoradi sites were analysed for individual locations in terms of their variation at different distances from the ground as well as for the various orientation of the antenna elements (vertically and horizontally polarised). These individual field strength values were time-averaged to give a single field strength value for each height. The field strength at 2.0 m, 1.7 m, 1.5 m and 1.0 m were then averaged spatially to give a single field strength value for each location. The far-field equivalent power densities for each location was calculated. The total exposure quotient at every location was determined. The electric field strength values for locations within each city were compared. An approximate calculation method was used to determine energy absorption by biological

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tissues as well as the SAR of the fields. The distance a plane-wave travels within a material until it decays to 1/e of its initial amplitude was determined the skin (dry and wet) and the eye (sclera and cornea). The electrical conductivity of the selected tissues was calculated. The worst-case scenario energies transmitted into human tissues have been estimated.

Within the limitations of the methodology used in the study, the exposure of humans in the study zones were ICNIRP compliant. Manhyia location recorded the highest spatial averaged electric field strength of 1181.8 ± 166.6 mVm^{-1} whilst Rawlings Park location recorded the least value of 3.14 ± 0.45 mVm^{-1}. The highest field strength was determined at an area 287.8 m above sea level. Results show that the rate of absorbing energy by human tissues depends on the tissue's relative permittivity, conductivity, frequency, density and the level of the ambient electric field.

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CHAPTER FIVE

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SUMMARY, CONCLUSION AND RECOMMENDATIONS

Overview

In this research work, the exposure of members of the public to RF emissions from sources between 87.5 MHz and 2.6 GHz has been assessed at 30 public places within Accra-Tema, Sekondi-Takoradi and Kumasi. Electric field strength produced by transmitting antenna systems were measured at 2.0 m, 1.7 m, 1.5 m and 1.0 m. The power densities produced at these locations, because of sources transmitting within the frequency band investigated, were calculated. The total exposure quotient (cumulative exposure) in these multi transmitter environments was also determined. Estimation of the electric field strength produced within human tissues because of their presence within the ambient fields was carried out. SAR values were calculated for the interaction of these fields with selected tissues and the worst-case scenario energies transmitted into selected tissues were estimated.

Summary

Within the limitations of the methodology employed in this work, the exposure of humans at the three study zones were ICNIRP compliant as the total exposure quotients (cumulative exposure) within each frequency band at each location is less than unity. However, some locations have relatively elevated field strength levels as compared with other study areas. No location has a maximum field strength level within all the six frequency bands (FM, VHF, etc.). Exposure of persons at Manhyia location to FM broadcast band electric fields was the maximum with spatial averaged plane-wave electric

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field strength of 1181.8 ± 166.6 mVm^{-1}. Dwellers at Rawlings Park location are exposed to the least spatial averaged electric fields from the FM broadcast band frequencies with field strength value of 3.14 ± 0.45 mVm^{-1}. The maximum plane-wave electric field strength was transmitted into wet skin with an approximate value of 0.227 ± 0.032 Vm^{-1} which is 2.28% more than that transmitted into dry skin. The SAR values ranged from 24.34 ± 3.43 μW/kg to 2.10E-05 ± 2.99E-06 μW/kg. The estimated maximum worst-case scenario energy associated with the transmitted electric fields was 1850.23 ± 261.13 MJ in dry skin. This value was 100 MJ more than the energy imparted to wet skin. The highest power density determined was 3.70 mW/m^2 at Manhyia location. The total exposure quotient varied from 4.43E-05 ± 6.25E-06 representing 0.004% of the recommended limit of unity to 2.78E+06 ± 5.03E-08.

Results indicated that the rate at which energy was absorbed by human tissues depends on the tissue's relative permittivity, its ability to conduct electricity, its density and the level of the ambient electric field as well as the frequency producing such fields. The levels of the electric fields in the multi-transmitter environments assessed were well within the recommended limits of ICNIRP. It was observed that plane-wave electric fields from lower frequency bands are more penetrating than at higher frequencies. This was evident in the skin-depth values obtained for the various frequencies. At 100 MHz (an FM radio frequency) the skin-depth is about three times larger than at 940 MHz (mobile telephony frequency) and about five times larger at 2.6 GHz. This means that the electric fields are three times more concentrated near the surface of the body at 940 MHz than at 100 MHz. It also means that

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internal organs of the body are subjected to higher fields at lower frequencies than at higher frequencies. Hence, the internal organs are more protected at higher frequencies than at lower frequencies. In this work, the highest electric field was determined at an FM frequency. The exposure of persons in Kumasi, Accra-Tema and Sekondi-Takoradi is within the recommended limits. Over time, the dominant sources of ambient RF energy in the environments assessed were found to be due to FM radio transmissions

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Conclusions

Humans, being bioelectrical systems, have brain and heart functionalities regulated by natural inbuilt bioelectrical signals. From the analysis done in this work, exposures to ambient artificial EMFs have the possibility of interacting with basic biological processes in the human body. Even though the levels reported in this work are far below the recommended limits put forth by ICNIRP as levels above which some biological effects are noticeable, there are reported biological effects that have occurred at levels similar to those reported in this work. Within a power density range of 0.003 to 0.05 μW/cm^2, Thomas, Heinrich, Von-Kries & Radon (2010) reported that a short-term exposure in children and adolescents aged between 8 - 17 yrs resulted in conduct problems in school (behavioural problems). In adults aged between 30 - 60 yrs chronic exposure to power density level of 0.005 μW/cm^2 caused sleep disturbances (Mohler, Frei, Braun-Fahrländer, Fröhlich, Neubauer, & Röösli, 2010). This work therefore concludes that until the current exposure standards are reviewed, RF emitting devices producing field strength and power density levels below the recommendations of ICNIRP are

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safe and the ambient RF levels in the Accra-Tema, Sekondi-Takoradi and Kumasi are considered safe for human exposure. However, RF emitting devices should be used with great precaution.

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The methodology developed and employed in this work may be potentially applied for improved exposure assessment in multi-transmitter environments. The work has extended the boundary of RF exposure assessment as it went beyond assessing ambient exposure parameters to include transmission of electric field strength and energy across air-tissue boundaries for four human tissues.

Recommendations

The increasing awareness of the possibility of RF radiations to cause malignant cancer has led to escalating concerns about the possible health effects that may arise as a consequence of exposure to ambient RF radiations. Following the classification of RF EMF by IARC as Group 2B in 2011, communities have resisted and continue to resist attempts by telecommunication companies to erect BTS within their communities. The demand for information about ambient electric field strength levels and the consequences of living within such fields for years is on the ascendency. Even though many experts in the non-ionizing radiation field have concluded that there is not enough evidence to prove that RF causes health problems other than a possible association with cancer (IARC, 2012), more needs to be known about the RF induced phenomena and their possible effects on human health and scientific equipment. In response to these concerns, the following recommendations have been made.

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As part of its corporate social responsibilities, Radiation Protection Institute (RPI) should offer RF safety education to the general public and make research findings readily available for public consumption. The annual assessment of telecommunication BTS should be extended to TV and FM transmission sites nationwide. RPI should lead research efforts to determine if the exposures of persons who reside in buildings with side-mounted antennas are within safe limits.

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NCA should collaborate with RPI in its ongoing efforts of undertaking research into the possible health effects of RF radiations. This will accelerate research in that direction and make more findings available for public consumption. NCA should make it mandatory for TV and FM broadcast stations to undertake RF safety assessment yearly. This will provide important information on the rate of increase of electric fields from their antennas.

EPA should support research into environmental impact of RF emissions levels within the environment to assure the populace that their exposure to ambient RF fields is within recommended bounds.

It is recommended to owners of FM radio and TV stations to appoint Radiation Protection Officers (RPO) responsible for ensuring the overall radiation safety of employees. Designers of FM radio and TV stations may consider design measures aimed at lowering electric field levels (exposure) while maintaining safe, secure and effective transmission of RF radiations. This can be achieved by building repeater stations.

In order to properly evaluate the exposure of humans to RF radiations in Ghana, research on the nature and propagation of electric fields at night should be carried out. Electric fields produced by indoor transmitting antennas

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used for WiFi networks at workplaces, homes and public places should be assessed to determine if the exposure of persons is within bounds or if the exposure can be made as low as reasonably allowable. More studies should be undertaken in Kumasi to further investigate the distribution of VHF TV band fields. Balconies of high-rising building should be centre of focus. University of Ghana Campus should be assessed to determine whether the exposure of persons on campus is as low as reasonably possible. Radiating antennas produce fields in the forward direction as well as in the sideways and backward directions known as side lobes and back lobes. Apartments, offices and rooftops of high-rising buildings hosting side-mounted antennas should be investigated to see if the levels of the electric fields from mounted antennas are within recommended limits and /or if such exposures can be made as low as reasonably possible.

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Chapter Summary

This chapter summarised the approach to the study and the findings made. Conclusions were drawn based on the findings. Recommendations were made to various stakeholders in the communication industry and for further study. The study concludes that the exposure of humans at the study locations is well within the limits recommended by ICNIRP guidelines. This study has extended the boundary of RF exposure assessment. It went beyond assessing ambient exposure parameters to include transmission of electric field strength and energy across air-tissue boundaries for four human tissues. It is recommended that the various stakeholders should collaborate to ensure safe

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usage of RF applications. More studies need to be carried out to enable us understand fully the RF phenomena in Ghana.

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Appendix A

Relevant Tables

Table A1- Quantities and Units used in Experimental Exposure Assessment

QUANTITY	SYMBOL	SI-UNIT	SYMBOL
Conductivity	σ	Siemens per meter	$S.m^{-1}$
Permittivity	ε	Farad per meter	$F.m^{-1}$
Current	I	ampere	A
Current density	J	Ampere per square meter	$A.m^{-2}$
Electric field strength	E	Volt per meter	$V.m^{-1}$
Power density	S	Watt per square meter	$W.m^{-2}$
Frequency	f	hertz	Hz
Impedance	Z	ohm	Ω
Magnetic field strength	H	ampere per kilogram	$A.kg^{-1}$
Propagation constant	k	Per meter	m^{-1}
Specific absorption	SA	Joule per kilogram	$J. kg^{-1}$
Specific absorption rate	SAR	Watt per kilogram	$W. kg^{-1}$
Wavelength	λ	meter	m
Magnetic flux density	B	tesla	T
Relative permeability	μ_r	-	-

Adapted from ICNIRP (2009a)

Table A2- The International Telecommunications Union (ITU) Categorization for Radio Waves

Designation	Abbreviation	Frequencies	Free-space Wavelengths
Very Low Frequency	VLF	9 kHz - 30 kHz	33 km - 10 km
Low Frequency	LF	30 kHz - 300 kHz	10 km - 1 km
Medium Frequency	MF	300 kHz - 3 MHz	1 km - 100 m
High Frequency	HF	3 MHz - 30 MHz	100 m - 10 m
Very High Frequency	VHF	30 MHz - 300 MHz	10 m - 1 m
Ultra-High Frequency	UHF	300 MHz - 3 GHz	1 m - 100 mm
Super High Frequency	SHF	3 GHz - 30 GHz	100 mm-10mm
Extremely High Frequency	EHF	30 GHz - 300 GHz	10 mm - 1 mm

Adapted from ITU (2008)

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Table A3- Frequency Bands used for Broadcasting of Television and Radio Signals

Designation	Frequency Range	Usage
Long wave	145.5 – 283.5 kHz	AM radio
Medium wave	526.5 – 1606.5 kHz	AM radio
Short wave	3.9 – 26.1 MHz	International radio
UHF (Bands IV and V)	470 – 854 MHz	Analogue and digital TV
VHF (Band II)	87.5 – 108 MHz	FM radio
VHF (Band III)	174 – 223 MHz	DAB and analogue/digital TV

Table A4- Basic Restrictions (BRs) for Time-Varying Electric and Magnetic Fields for Frequencies up to 10 GHz.

Exposure characteristics	Frequency range	Current density for head and trunk (mAm^{-2}) (ms)	Whole-body average SAR (WKg^{-1})	Localised SAR(head and trunk) (WKg^{-1})	Localised SAR(limbs) (WKg^{-1})
Occupational exposure	Up to 1 Hz	40	-	-	-
	1 – 4 Hz	40/f	-	-	-
	4 Hz – 1kHz	10	-	-	-
	1-100 kHz	f/100	-	-	-
	100kHz-10MHz	f/100	0.4	10	20
	10MHz-10GHz	-	0.4	10	20
General public exposure	Up to 1 Hz	8	-	-	-
	1 – 4 Hz	8/f	-	-	-
	4 Hz – 1kHz	2	-	-	-
	1 – 100 kHz	f/500	-	-	-
	100 kHz – 10 MHz	f/500	0.08	2	4
	10 MHz – 10 GHz	-	0.08	2	4

(ICNIRP, 1998)

Note:

1. f is the frequency in hertz.

2. Because of electrical inhomogeneity of the body, current densities should be averaged over a cross-section of 1 cm^2 perpendicular to the current direction.

3. For frequencies up to 100 kHz, peak current density values can be obtained by multiplying the rms value by $\sqrt{2}$ (~1.414). For pulses of duration t_p the equivalent frequency to apply in the basic restrictions should be calculated as $f = 1/(2t_p)$.

4. For frequencies up to 100 kHz and for pulsed magnetic fields, the maximum current density associated with the pulses can be calculated from the rise/fall times and the maximum rate of change of magnetic flux density. The induced current density can then be compared with the appropriate basic restriction.

5. All SAR values are to be averaged over any 6-min period.

6. Localized SAR averaging mass is any 10 g of contiguous tissue; the maximum SAR so

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obtained should be the value used for the estimation of exposure.

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7. For pulses of duration t_p the equivalent frequency to apply in the basic restrictions should be calculated as $f = 1/(2t_p)$. Additionally, for pulsed exposures in the frequency range 0.3 to 10 GHz and for localized exposure of the head, in order to limit or avoid auditory effects caused by thermoelastic expansion, an additional basic restriction is recommended. This is that the SA should not exceed 10 mJ kg^{-1} for workers and 2 mJ kg^{-1} for the general public, averaged over 10 g tissue.

Table A5- Reference Levels for General Public Exposure to Time-Varying Electric and Magnetic Fields (unperturbed rms values).[a]

Frequency range	E-field strength (Vm^{-1})	H-field strength (Am^{-1})	B-field (μT)	Equivalent plane-wave power density S_{eq} (Wm^{-2})
up to 1 Hz	-	3.2×10^4	4×10^4	-
1–8 Hz	10,000	$3.2 \times 10^4/f^2$	$4 \times 10^4/f^2$	-
8–25 Hz	10,000	$4{,}000/f$	$5{,}000/f$	-
0.025–0.8 kHz	$250/f$	$4/f$	$5/f$	-
0.8–3 kHz	$250/f$	5	6.25	-
3–150 kHz	87	5	6.25	-
0.15–1 MHz	87	$0.73/f$	$0.92/f$	-
1–10 MHz	$87/f^{1/2}$	$0.73/f$	$0.92/f$	-
10–400 MHz	28	0.073	0.092	2
400–2,000 MHz	$1.375f^{1/2}$	$0.0037f^{1/2}$	$0.0046/f^{1/2}$	$f/200$
2–300 GHz	61	0.16	0.20	10

Source: (ICNIRP, 1998)

[a] Note:

1. f as indicated in the frequency range column.
2. Provided that basic restrictions are met and adverse indirect effects can be excluded, field strength values can be exceeded.
3. For frequencies between 100 kHz and 10 GHz, S_{eq}, E^2, H^2, and B^2 are to be averaged over any 6-min period.
4. For peak values at frequencies up to 100 kHz
5. For peak values at frequencies exceeding 100 kHz see Figs. 1 and 2. Between 100 kHz and 10 MHz, peak values for the field strengths are obtained by interpolation from the 1.5-fold peak at 100 kHz to the 32-fold peak at 10 MHz. For frequencies exceeding 10 MHz it is suggested that the peak equivalent plane-wave power density, as averaged over the pulse width does not exceed 1,000 times the S_{eq} restrictions, or that the field strength does not exceed 32 times the field strength exposure levels given in the table.
6. For frequencies exceeding 10 GHz, S_{eq}, E^2, H^2, and B^2 are to be averaged over any 68/f 1.05-min period (f in GHz).
7. No E-field value is provided for frequencies, <1 Hz, which are effectively static electric fields. perception of surface electric charges will not occur at field strengths less than 25 kVm^{-1}. Spark discharges causing stress or annoyance should be avoided.

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Table A6- Detailed Site Characteristics

Measurement Locations	GPS Coordinate	Altitude/m	№ of BTS within a km radius	Area classification
Abeka Junction	N5.59985°, W0.22411°	19.3	4	Commercial/Residential
Airport Aviance	N5.59828°, W0.17586°	58.5	10	Commercial
Comet Hills	N5.72476°, W0.24929°	277.6	10	Residential
Korle-Bu Teaching Hospital	N5.53879°, W0.22932°	18.1	3	Hospital
McCarthy Hill	N5.56749°, W0.29579°	94.0	6	residential
Rawlings Park	N5.54609°, W0.20746°	16.1	6	Commercial
Sakumono Total Filling Station	N5.62158°, W0.07054°	35.8	4	Commercial/Residential
Tema Community One	N5.64727°, W0.00202°	7.6	6	Commercial/Residential
Tema Roundabout	N5.68532°, W0.01757°	37.3	9	Commercial
University Of Ghana	N5.64989°, W0.19503°	143.3	8	School/residential
Adum	N6.68804°, W1.62300°	271.1	12	Commercial
Airport Roundabout	N6.70799°, W1.59852°	255.1	6	Commercial
Amakom Baba Yara Stadium	N6.66187°, W1.61732°	267.3	5	Residential/commercial/recreational
Bremang	N6.74732°, W1.63981°	254.0	5	Residential/commercial
Manhyia	N6.70433°, W1.61185°	287.8	5	Residential/Hospital
Melcom	N6.66187°, W1.61732°	242.3	4	Residential/commercial/recreational
Prempeh College	N6.70102°, W1.64816°	281.8	7	Residential/School
Santasi Roundabout	N6.67175°, W1.63859°	253.9	6	Residential/commercial
UEW College of Technology	N6.69710°, W1.68299°	254.6	5	Residential/School
Wesley Girls SHS	N6.71772°, W1.62224°	279.8	3	School/residential
Anaji Westline	N4.93044°, W1.78257°	19.9	9	Residential
DuPaul	N4.90689°, W1.79288°.	26.1	3	Residential
Essipon Sekondi	N4.96439°, W1.69409°	19.6	6	Residential
Fort-Orange Sekondi	N4.93544°, W1.70733°	19.1	7	Residential
Galaxy	N4.91424°, W1.79364°	21.3	4	Residential/Commercial
Habour	N4.88198°, W1.74859°	3.6	4	Commercial
Lagos Town	N4.90874°, W1.77873°	10.3	4	Residential
Market Circle	N4.90058°, W1.76434°	27.3	5	Commercial/Residential
T-Technical University	N4.91075°, W1.75631°	20.3	4	School/Residential
Vienna City Round about	N4.88629°, W1.75975°	14.1	5	Recreational/Residential

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Table A7- Summary of Numerical Results for Baba Yara Stadium

Source	Frequency Band (MHz)	Reference level(V/m)	Height(m)	Measured value(mV/m)	Exposure quotient	Power density/μWm²	Spatial Average (mV/m)
FM broadcast	87.5 - 108	28	1.0	222.22 ± 32.00	6.30E-05 ± 8.82E-07	130.99 ± 18.86	304.14 ± 43.8
			1.5	276.72 ± 39.85	9.77E-05 ± 1.37E-06	203.11 ± 29.25	
			1.7	327.35 ± 47.14	1.37E-04 ± 1.92E-06	284.24 ± 40.93	
			2.0	**369.97 ± 53.28**	**1.75E-04 ± 2.45E-06**	**363.07 ± 52.28**	
VHF TV	174 - 230	28	1.0	579.41 ± 83.44	4.28E-04 ± 5.99E-06	890.49 ± 128.23	458.25 ± 65.9
			1.5	316.24 ± 45.54	1.28E-04 ± 1.79E-06	265.27 ± 38.20	
			1.7	437.43 ± 62.99	2.44E-04 ± 3.42E-06	507.55 ± 73.09	
			2.0	**461.40 ± 66.44**	**2.72E-04 ± 3.81E-06**	**564.69 ± 81.32**	
UHF TV	470 - 862	30	1.0	146.17 ± 21.05	2.37E-05 ± 3.32E-07	56.67 ± 8.16	158.80 ± 22.9
			1.5	165.16 ± 23.78	3.03E-05 ± 4.24E-07	72.35 ± 10.42	
			1.7	146.94 ± 21.16	2.40E-05 ± 3.36E-07	57.27 ± 8.25	
			2.0	**175.02 ± 25.20**	**3.40E-05 ± 4.76E-07**	**81.25 ± 11.70**	
GSM 900	925 - 960	42	1.0	83.98 ± 12.09	4.00E-06 ± 5.60E-08	18.71 ± 2.69	93.49 ± 13.4
			1.5	93.11 ± 13.41	4.92E-06 ± 6.89E-08	23.00 ± 3.31	
			1.7	95.54 ± 13.76	5.17E-06 ± 7.24E-08	24.21 ± 3.49	
			2.0	**100.55 ± 14.48**	**5.73E-06 ± 8.02E-08**	**26.82 ± 3.86**	
GSM 1800	1805 - 1910	58	1.0	83.82 ± 12.07	2.09E-06 ± 2.93E-08	18.71 ± 2.68	61.40 ± 8.8
			1.5	54.21 ± 7.81	8.74E-07 ± 1.22E-08	7.80 ± 1.12	
			1.7	45.82 ± 6.60	6.24E-07 ± 8.74E-09	5.57 ± 0.80	
			2.0	**54.94 ± 7.91**	**8.97E-07 ± 1.26E-08**	**8.01 ± 1.15**	
UMTS(WCDMA/3G)	2110 - 2170	61	1.0	41.39 ± 5.96	4.60E-07 ± 6.44E-09	4.55 ± 0.65	39.05 ± 5.6
			1.5	42.18 ± 6.07	4.78E-07 ± 6.69E-09	4.72 ± 0.68	
			1.7	30.29 ± 4.36	2.47E-07 ± 3.46E-09	2.44 ± 0.35	
			2.0	**41.10 ± 5.92**	**4.54E-07 ± 6.36E-09**	**4.48 ± 0.65**	

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Table A8- Summary of Numerical Results for Meicom

Band	Frequency (MHz)	Reference level (V/m)	Height (m)	Measured value (mV/m)	Exposure quotient	Power density (µW/m²)	Spatial average (mV/m)
			1.0	109.04 ± 15.54	6.38E-06 ± 8.93E-07	31.54 ± 4.49	
			1.5	131.02 ± 18.67	9.78E-06 ± 1.37E-06	45.53 ± 6.49	
FM broadcast	87.5 - 108	28	1.7	83.22 ± 11.86	4.11E-06 ± 5.75E-07	8.54 ± 1.22	**102.27 ± 14.63**
			2.0	**76.55 ± 10.91**	**6.38E-06 ± 8.93E-07**	**13.30 ± 1.90**	
			1.0	117.99 ± 16.81	4.68E-08 ± 6.55E-09	36.93 ± 5.26	
			1.5	117.35 ± 16.72	3.3E-08 ± 4.62E-09	36.52 ± 5.20	
VHF TV	174 - 230	28	1.7	93.41 ± 13.31	6.51E-08 ± 9.11E-09	23.14 ± 3.30	**103.47 ± 14.72**
			2.0	**80.04 ± 11.41**	**3.26E-08 ± 4.56E-09**	**16.99 ± 2.42**	
			1.0	118.26 ± 16.85	4.3E-06 ± 6.02E-07	37.10 ± 5.29	
			1.5	145.67 ± 20.76	6.35E-06 ± 8.89E-07	56.29 ± 8.02	
UHF TV	470 - 862	30	1.7	114.90 ± 16.37	1.6E-05 ± 2.24E-06	35.02 ± 4.99	**125.53 ± 17.94**
			2.0	**120.92 ± 17.23**	**6.45E-06 ± 9.03E-07**	**38.78 ± 5.53**	
			1.0	78.70 ± 11.21	4.45E-05 ± 6.23E-06	16.42 ± 2.34	
			1.5	93.11 ± 13.27	6.03E-05 ± 8.44E-06	23.00 ± 3.27	
GSM 900	925 - 960	42	1.7	86.98 ± 12.39	6.06E-05 ± 8.48E-06	20.07 ± 2.86	**93.49 ± 13.33**
			2.0	**111.95 ± 15.95**	**5.68E-05 ± 7.95E-06**	**33.24 ± 4.74**	
			1.0	43.86 ± 6.25	2.02E-05 ± 2.83E-06	5.10 ± 0.73	
			1.5	54.21 ± 7.72	2.43E-05 ± 3.40E-06	7.80 ± 1.11	
GSM 1800	1805 - 1910	58	1.7	85.42 ± 12.17	1.73E-05 ± 2.42E-06	19.35 ± 2.76	**61.40 ± 8.75**
			2.0	**54.07 ± 7.70**	**1.99E-05 ± 2.79E-06**	**7.75 ± 1.11**	
			1.0	232.95 ± 33.20	4.60E-05 ± 6.44E-06	143.94 ±20.51	
			1.5	98.85 ± 14.09	2.14E-06 ± 3.00E-07	25.92 ± 3.69	
UMTS (WCDMA/3G)	2110 - 2170	61	1.7	81.07 ± 11.55	9.5E-06 ± 1.33E-06	17.43 ± 2.48	**139.73 ± 19.94**
			2.0	**86.53 ± 12.33**	**5.36E-06 ± 7.50E-07**	**19.86 ± 2.83**	

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Table A9- Summary of Numerical Results for Santasi Roundabout

Band	Frequency (MHz)	Reference level (V/m)	Height (m)	Measured value (mV/m)	Exposure quotient	Power density (µW/m²)	Spatial average (mV/m)
FM broadcast	87.5 - 108	28	1.0	222.22 ± 31.64	6.30E-05 ± 8.82E-06	130.99 ± 18.65	**284.54 ± 40.55**
			1.5	276.72 ± 39.40	9.77E-05 ± 1.37E-05	203.11 ± 28.92	
			1.7	312.78 ± 44.54	1.25E-04 ± 1.75E-05	259.50 ± 36.95	
			2.0	**316.35 ± 45.05**	**1.28E-04 ± 1.79E-05**	**265.46 ± 37.80**	
VHF TV	174 - 230	28	1.0	118.38 ± 16.86	1.79E-05 ± 2.51E-06	37.17 ± 5.29	**103.33 ± 14.72**
			1.5	117.04 ± 16.67	1.75E-05 ± 2.45E-06	36.34 ± 5.17	
			1.7	93.09 ± 13.26	1.11E-05 ± 1.55E-06	22.99 ± 3.27	
			2.0	**79.56 ± 11.33**	**8.07E-06 ± 1.13E-06**	**16.79 ±2.39**	
UHF TV	470 - 862	30	1.0	146.17 ± 20.81	2.37E-05 ± 3.32E-06	56.67 ± 8.07	**158.77 ± 22.62**
			1.5	165.15 ± 23.52	3.03E-05 ± 4.24E-06	72.35 ± 10.30	
			1.7	146.92 ± 20.92	2.40E-05 ± 3.36E-06	57.26 ± 8.15	
			2.0	**174.97 ± 24.92**	**3.40E-05 ± 4.76E-06**	**81.21 ± 11.56**	
GSM 900	925 - 960	42	1.0	81.39 ± 11.59	3.76E-06 ± 5.26E-07	17.57 ± 2.50	**248.30 ± 35.38**
			1.5	328.45 ± 46.77	6.12E-05 ± 8.57E-06	286.15 ± 40.75	
			1.7	363.48 ± 51.76	7.49E-05 ± 1.05E-05	350.44 ± 49.90	
			2.0	**375.61 ± 53.49**	**8.00E-05 ± 1.12E-05**	**374.23 ± 53.29**	
GSM 1800	1805 - 1910	58	1.0	83.82 ± 11.94	2.09E-06 ± 2.93E-07	18.64 ± 2.65	**162.04 ± 23.09**
			1.5	180.56 ± 25.71	9.69E-06 ± 1.36E-06	86.48 ± 12.31	
			1.7	175.73 ± 25.02	9.18E-06 ± 1.29E-06	81.91 ± 11.66	
			2.0	**185.78 ± 26.46**	**1.03E-05 ± 1.44E-06**	**91.55 ± 13.04**	
UMTS (WCDMA/3G)	2110 - 2170	61	1.0	41.45 ± 5.10	4.62E-07 ± 6.36E-08	4.56 ± 0.64	**39.07 ± 5.56**
			1.5	42.18 ± 6.01	4.78E-07 ± 6.69E-08	4.72 ± 0.67	
			1.7	30.29 ± 4.31	2.47E-07 ± 3.46E-08	2.43 ± 0.35	
			2.0	**41.10 ± 5.85**	**4.54E-07 ± 6.36E-08**	**4.48 ± 0.64**	

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Table A10- Summary of Numerical Results for Bremang

Band	Frequency (MHz)	Reference level (V/m)	Height (m)	Measured value (mV/m)	Exposure quotient	Power density (μW/m²)	Spatial Average (mV/m)
			1.0	15.48 ± 2.20	3.06E-07 ± 4.28E-08	0.64 ± 0.09	
			1.5	16.13 ± 2.30	3.32E-07 ± 4.65E-08	0.69 ± 0.10	
FM broadcast	87.5 - 108	28	1.7	14.33 ± 2.04	2.62E-07 ± 3.67E-08	0.54 ± 0.08	**14.64 ± 2.11**
			2.0	**12.33 ± 1.76**	**1.94E-07 ± 2.72E-08**	**0.40 ± 0.06**	
			1.0	6.816 ± 0.97	5.93E-08 ± 8.30E-09	0.12 ± 0.02	
			1.5	8.092 ± 1.15	8.35E-08 ± 8.30E-09	0.17 ± 0.02	
VHF TV	174 - 230	28	1.7	19.44 ± 2.77	4.82E-07 ± 6.75E-08	1.00 ± 0.14	**12.68 ± 1.82**
			2.0	**12.36 ± 1.76**	**1.95E-07 ± 2.73E-08**	**0.41 ± 0.06**	
			1.0	48.23 ± 6.87	2.58E-06 ± 3.61E-07	6.17 ± 0.88	
			1.5	59.98 ± 8.54	4.00E-06 ± 5.60E-07	9.54 ± 1.36	
UHF TV	470 - 862	30	1.7	45.30 ± 6.45	2.28E-06 ± 3.19E-07	5.44 ± 0.78	**50.96 ± 7.23**
			2.0	**49.09 ± 6.99**	**2.68E-06 ± 3.75E-07**	**6.39 ± 0.91**	
			1.0	82.29 ± 11.72	3.84E-06 ± 5.38E-07	17.96 ± 2.56	
			1.5	253.31 ± 36.07	3.64E-05 ± 5.10E-06	170.20 ± 24.24	
GSM 900	925 - 960	42	1.7	179.36 ± 25.54	1.82E-05 ± 2.55E-06	85.33 ± 12.15	**180.96 ± 25.71**
			2.0	**166.97 ± 23.78**	**1.58E-05 ± 2.21E-06**	**73.95 ± 10.53**	
			1.0	95.10 ± 13.54	2.69E-06 ± 3.77E-07	23.99 ± 3.42	
			1.5	80.97 ± 11.53	1.95E-06 ± 2.73E-07	17.39 ± 2.48	
GSM 1800	1805 - 1910	58	1.7	88.88 ± 12.66	2.35E-06 ± 3.29E-07	20.95 ± 2.98	**85.86 ± 12.23**
			2.0	**77.38 ± 11.02**	**1.78E-06 ± 2.49E-07**	**15.88 ± 2.26**	
			1.0	35.75 ± 5.07	3.43E-07 ± 4.88E-08	3.39 ± 0.48	
			1.5	35.64 ± 5.06	3.41E-07 ± 4.85E-08	3.37 ± 0.47	
UMTS	2110 - 2170	61	1.7	37.87 ± 5.38	3.85E-07 ± 5.47E-08	3.80 ± 0.35	**37.33 ± 5.30**
(WCDMA/3G)			2.0	39.92 ± 5.67	4.28E-07 ± 6.08E-08	4.23 ± 0.60	

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Table A11- Summary of Numerical Results for Kumasi Wesley Girls High

Band	Frequency (MHz)	Reference level (V/m)	Height (m)	Measured value (mV/m)	Exposure quotient	Power density (μW/m²)	Spatial Average (mV/m)
FM broadcast	87.5 - 108	28	1.0	32.46 ± 4.67	1.34E-06 ± 1.65E-07	2.79 ± 0.40	**31.12 ± 4.48**
			1.5	35.66 ± 5.14	1.62E-06 ± 1.99E-07	3.38 ± 0.49	
			1.7	32.21 ± 4.64	1.32E-06 ± 1.62E-07	2.75 ± 0.40	
			2.0	**22.63 ± 3.26**	**6.53E-07 ± 8.03E-08**	**1.31 ± 0.20**	
VHF TV	174 - 230	28	1.0	8.34 ± 1.20	8.88E-08 ± 1.09E-08	0.18 ± 0.03	**9.86 ± 1.42**
			1.5	13.29 ± 1.91	2.25E-07 ± 2.77E-08	0.47 ± 0.07	
			1.7	8.21 ± 1.18	8.60E-08 ± 1.06E-08	0.18 ± 0.03	
			2.0	**8.68 ± 1.25**	**9.62E-08 ± 1.18E-08**	**2.00 ± 0.03**	
UHF TV	470 - 862	30	1.0	76.42 ± 1.00	6.49E-06 ± 7.98E-07	15.49 ± 2.23	**101.12 ± 14.56**
			1.5	125.35 ± 18.05	1.75E-05 ± 2.15E-06	41.67 ± 6.00	
			1.7	98.76 ± 14.22	1.08E-05 ± 1.33E-06	25.87 ± 3.73	
			2.0	**98.76 ± 14.22**	**1.08E-05 ± 1.33E-06**	**25.87 ± 3.73**	
GSM 900	925 - 960	42	1.0	144.81 ± 20.85	1.19E-05 ± 1.46E-06	55.62 ± 8.01	**143.32 ± 20.64**
			1.5	136.58 ± 19.67	1.06E-05 ± 1.30E-06	49.48 ± 7.13	
			1.7	126.74 ± 18.25	9.11E-06 ± 1.12E-06	42.61 ± 6.14	
			2.0	**162.78 ± 23.44**	**1.50E-05 ± 1.85E-06**	**70.28 ± 10.12**	
GSM 1800	1805 - 1910	58	1.0	34.29 ± 4.94	3.49E-07 ± 4.29E-08	3.12 ± 0.45	**55.76 ± 8.03**
			1.5	82.41 ± 11.87	2.02E-06 ± 2.48E-07	18.01 ± 2.59	
			1.7	49.57 ± 7.14	7.30E-07 ± 8.98E-08	6.52 ± 0.94	
			2.0	**44.84 ± 6.46**	**5.98E-07 ± 7.36E-08**	**5.33 ± 0.77**	
UMTS(WCDMA/3G)	2110 - 2170	61	1.0	269.18 ± 38.76	1.95E-05 ± 2.40E-06	192.20 ± 27.68	**196.83 ± 28.34**
			1.5	212.01 ± 30.53	1.21E-05 ± 1.49E-06	119.23 ± 17.17	
			1.7	126.13 ± 18.16	4.28E-06 ± 5.26E-07	42.20 ± 6.08	
			2.0	**146.87 ± 21.15**	**5.80E-06 ± 7.13E-07**	**57.22 ± 8.24**	

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Table A12- Summary of Numerical Results for Airport Roundabout

Band	Frequency (MHz)	Reference level (V/m)	Height (m)	Measured value (mV/m)	Exposure quotient	Power density (μW/m²)	Spatial Average (mV/m)
			1.0	140.45 ± 20.08	2.52E-05 ± 3.60E-06	52.32 ± 7.48	
			1.5	115.49 ± 16.52	1.70E-05 ± 2.43E-06	35.38 ± 5.06	
FM broadcast	87.5 - 108	28	1.7	86.05 ± 12.31	9.45E-06 ± 1.35E-06	19.64 ± 2.81	**120.05 ± 17.17**
			2.0	**131.05 ± 18.74**	**2.19E-05 ± 3.13E-06**	**45.55 ± 6.51**	
			1.0	14.50 ± 2.07	2.68E-07 ± 3.83E-08	0.56 ± 0.08	
			1.5	13.35 ± 1.91	2.27E-07 ± 3.25E-08	0.47 ± 0.07	
VHF TV	174 - 230	28	1.7	9.57 ± 1.37	1.17E-07 ± 1.67E-08	0.24 ± 0.03	**14.60 ± 2.09**
			2.0	**19.30 ± 2.76**	**4.75E-07 ± 6.79E-08**	**0.99 ± 0.14**	
			1.0	34.99 ± 5.00	1.36E-06 ± 1.94E-07	3.25 ± 0.46	
			1.5	43.53 ± 6.22	2.11E-06 ± 3.02E-07	5.03 ± 0.72	
UHF TV	470 - 862	30	1.7	47.29 ± 6.76	2.48E-06 ± 3.55E-07	5.93 ± 0.85	**43.11 ± 6.16**
			2.0	**45.59 ± 6.52**	**2.31E-06 ± 3.30E-07**	**5.51 ± 0.79**	
			1.0	71.56 ± 10.23	2.90E-06 ± 4.15E-07	13.58 ± 1.94	
			1.5	73.86 ± 10.56	3.09E-06 ± 4.42E-07	14.47 ± 2.07	
GSM 900	925 - 960	42	1.7	175.06 ± 25.03	1.74E-05 ± 2.49E-06	81.29 ± 11.62	**173.44 ± 24.80**
			2.0	**281.27 ± 40.22**	**4.48E-05 ± 6.41E-06**	**209.85 ± 30.01**	
			1.0	85.07 ± 12.17	2.15E-06 ± 3.07E-07	19.20 ± 2.75	
			1.5	57.76 ± 8.26	9.92E-07 ± 1.42E-07	8.85 ± 1.27	
GSM 1800	1805-1910	58	1.7	91.93 ± 13.15	2.51E-06 ± 3.59E-07	22.42 ± 3.21	**76.70 ± 10.97**
			2.0	**67.13 ± 9.60**	**1.34E-06 ± 1.92E-07**	**11.95 ± 1.71**	
			1.0	413.85 ± 59.18	4.60E-05 ± 6.58E-06	454.30 ± 64.96	
			1.5	80.56 ± 11.52	1.74E-06 ± 2.49E-07	17.21 ± 2.46	
UMTS(WCDMA/3G)	2110-2170	61	1.7	70.56 ± 10.09	1.34E-06 ± 1.92E-07	13.21 ± 1.89	**216.47 ± 30.96**
			2.0	**68.50 ± 9.80**	**1.26E-06 ± 1.80E-07**	**12.45 ± 1.78**	

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Table A13- Summary of numerical results for Adum

Band	Frequency (MHz)	Reference level (V/m)	Height (m)	Measured value (mV/m)	Exposure quotient	Power density (μW/m²)	Spatial average (mV/m)
			1.0	599.33 ± 84.81	4.58E-04 ± 6.46E-05	952.78 ± 134.82	
			1.5	563.06 ± 79.67	4.04E-04 ± 5.70E-05	840.95 ± 118.99	
FM broadcast	87.5 - 108	28	1.7	785.73 ± 111.18	7.87E-04 ± 1.11E-05	1637.59 ± 231.72	**627.57 ± 88.80**
			2.0	**530.81 ± 75.11**	**3.59E-04 ± 5.06E-05**	**747.37 ± 105.75**	
			1.0	122.23 ± 17.30	1.90E-05 ± 2.68E-06	39.63 ± 5.61	
			1.5	107.20 ± 15.17	1.47E-05 ± 2.07E-06	30.48 ± 4.31	
VHF TV	174 - 230	28	1.7	78.03 ± 11.04	7.77E-06 ± 1.10E-06	16.15 ± 2.29	**101.14 ± 14.31**
			2.0	**91.66 ± 12.97**	**1.07E-05 ± 1.51E-06**	**22.29 ± 3.15**	
			1.0	94.07 ± 13.31	9.83E-06 ± 1.39E-06	23.47 ± 3.32	
			1.5	86.04 ± 12.17	8.23E-06 ± 1.16E-06	19.64 ± 2.78	
UHF TV	470 - 862	30	1.7	91.06 ± 12.88	9.21E-06 ± 1.30E-06	21.99 ± 3.11	**103.01 ± 14.58**
			2.0	**133.79 ± 18.93**	**1.99E-05 ± 2.81E-06**	**47.48 ± 6.72**	
			1.0	71.56 ± 10.13	2.90E-06 ± 4.09E-07	13.58 ± 1.92	
			1.5	73.86 ± 10.45	3.00E-06 ± 4.23E-07	14.47 ± 2.05	
GSM 900	925 - 960	42	1.7	175.06 ± 24.77	1.74E-05 ± 2.45E-06	81.29 ± 11.50	**173.44 ± 24.54**
			2.0	**281.27 ± 39.80**	**4.4E-05 ± 6.20E-06**	**209.85 ± 29.69**	
			1.0	151.90 ± 21.49	6.86E-06 ± 9.67E-07	61.20 ± 8.66	
			1.5	228.15 ± 32.28	1.55E-05 ± 2.19E-06	138.07 ± 19.54	
GSM 1800	1805-1910	58	1.7	199.84 ± 28.28	1.19E-05 ± 1.68E-06	105.93 ± 14.99	**191.89 ± 27.15**
			2.0	**179.52 ± 25.40**	**9.58E-06 ± 1.35E-06**	**85.48 ± 12.10**	
			1.0	413.85 ± 58.56	4.62E-05 ± 6.51E-06	454.30 ± 64.28	
			1.5	91.33 ± 12.92	2.24E-06 ± 3.16E-07	22.13 ± 3.13	
UMTS (WCDMA/3G)	2110-2170	61	1.7	103.10 ± 14.59	2.86E-06 ± 4.03E-07	28.20 ± 3.99	**230.03 ± 32.55**
			2.0	**146.34 ± 20.71**	**5.76E-06 ± 8.12E-07**	**56.80 ± 8.04**	

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Table A14- Summary of Numerical Results for Manhyia

Band	Frequency (MHz)	Reference level (V/m)	Height (m)	Measured value (mV/m)	Exposure quotient	Power density (μWm²)	Spatial average (mV/m)
			1.0	1237.39 ± 174.47	1.95E-0 ± 2.75E-04	4061.36 ± 572.65	
			1.5	1137.58 ± 160.40	1.65E-03 ± 2.33E-04	3432.59 ± 484.00	
FM broadcast	87.5 - 108	28	1.7	1218.15 ± 171.76	1.89E-03 ± 2.66E-04	3936.05 ± 554.98	**1181.88 ± 166.65**
			2.0	**1130.61 ± 159.42**	**1.63E-03 ± 2.30E-04**	**3390.66 ± 478.08**	
			1.0	8.34 ± 1.18	8.88E-08 ± 1.25E-08	0.18 ± 0.03	
			1.5	13.29 ± 1.87	2.25E-07 ± 3.17E-08	0.47 ± 0.07	
VHF TV	174 - 230	28	1.7	8.21 ± 1.16	8.60E-08 ± 1.21E-08	0.18 ± 0.03	**9.86 ± 1.39**
			2.0	**8.68 ± 1.22**	**9.62E-08 ± 1.36E-08**	**0.20 ± 0.03**	
			1.0	299.96 ± 42.29	1.02E-04 ± 1.44E-05	238.66 ± 33.65	
			1.5	125.35 ± 17.67	1.75E-05 ± 2.47E-06	41.68 ± 5.88	
UHF TV	470 - 862	30	1.7	190.21 ± 26.82	4.02E-05 ± 5.67E-06	95.97 ± 13.53	**194.69 ± 27.45**
			2.0	**98.76 ± 13.93**	**1.08E-05 ± 1.52E-06**	**25.87 ± 3.65**	
			1.0	289.29 ± 40.79	4.74E-05 ± 6.68E-06	221.99 ± 31.30	
			1.5	291.32 ± 41.08	4.81E-05 ± 6.78E-06	225.11 ± 31.74	
GSM 900	925 - 960	42	1.7	347.23 ± 48.96	6.84E-05 ±9.64E-06	319.81 ± 45.09	**284.44 ± 40.11**
			2.0	**185.80 ± 26.20**	**1.96E-05 ± 2.76E-06**	**91.57 ± 12.91**	
			1.0	33.22 ± 4.68	3.28E-07 ± 4.62E-08	2.93 ± 0.41	
			1.5	82.22 ± 11.60	2.01E-06 ± 2.83E-07	17.95 ± 2.53	
GSM 1800	1805 - 1910	58	1.7	49.29 ± 6.95	7.22E-07 ± 1.02E-07	6.44 ± 0.91	**55.45 ± 7.82**
			2.0	**44.70 ± 6.30**	**5.94E-07 ± 8.38E-08**	**5.30 ± 0.75**	
			1.0	235.45 ± 33.20	1.49E-05 ± 2.10E-06	147.05 ± 20.73	
			1.5	212.10 ± 29.91	1.21E-05 ± 1.71E-06	119.33 ± 16.83	
UMTS (WCDMA/3G)	2110 - 2170	61	1.7	125.89 ± 17.75	4.26E-06 ± 6.01E-07	42.04 ± 5.93	**185.59 ± 26.17**
			2.0	**146.64 ± 20.68**	**5.78E-06 ± 8.15E-07**	**57.04 ± 8.04**	

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Table A15- Summary of Numerical Results for UEW College of Technology

Band	Frequency (MHz)	Reference level (V/m)	Height (m)	Measured value (mV/m)	Exposure quotient	Power density (µW/m²)	Spatial Average (mV/m)
			1.0	47.89 ± 6.87	2.93E-06 ± 4.20E-07	6.08 ± 0.87	
			1.5	36.24 ± 5.20	1.67E-06 ± 2.40E-07	3.48 ± 0.50	
FM broadcast	87.5 - 108	28	1.7	51.12 ± 7.34	3.33E-06 ± 4.78E-07	6.93 ± 0.99	**45.58 ± 6.54**
			2.0	**45.73 ± 6.56**	**2.67E-06 ± 3.83E-07**	**5.55 ± 0.80**	
			1.0	9.18 ± 1.32	1.07E-07 ±1.54E-08	0.22 ± 0.03	
			1.5	13.29 ± 1.91	2.25E-07 ±3.23E-08	0.47 ± 0.07	
VHF TV	174 - 230	28	1.7	8.21 ± 1.18	8.60E-08 ±1.23E-08	0.18 ± 0.03	**10.05 ± 1.44**
			2.0	**8.68 ± 1.25**	**9.62E-08 ±1.38E-08**	**0.20 ± 0.03**	
			1.0	42.45 ± 6.09	2.00E-06 ± 2.87E-07	4.78 ± 0.69	
			1.5	37.3 ± 5.35	1.55E-06 ±2.22E-07	3.69 ± 0.53	
UHF TV	470 - 862	30	1.7	49.45 ± 7.10	2.72E-06 ±3.90E-07	6.49 ± 0.93	**43.94 ± 6.31**
			2.0	**45.66 ± 6.55**	**2.32E-06 ±3.33E-07**	**5.53 ± 0.79**	
			1.0	110.69 ± 15.88	6.95E-06 ±9.97E-07	32.50 ± 4.66	
			1.5	115.49 ± 16.57	7.56E-06 ±1.08E-06	35.38 ± 5.08	
GSM 900	925 - 960	42	1.7	102.16 ± 14.66	5.92E-06 ±8.50E-07	27.68 ± 3.97	**116.28 ± 16.69**
			2.0	**134.37 ± 19.28**	**1.02E-05 ±1.46E-06**	**47.89 ± 6.87**	
			1.0	56.33 ± 8.08	9.43E-07 ±1.35E-07	8.42 ± 1.21	
			1.5	88.31 ± 12.67	2.32E-06 ±3.33E-07	20.69 ± 2.97	
GSM 1800	1805 - 1910	58	1.7	49.57 ± 7.11	7.30E-07 ±1.05E-07	6.52 ± 0.94	**63.65 ± 9.13**
			2.0	**52.73 ± 7.57**	**8.26E-07 ±1.19E-07**	**7.38 ± 1.06**	
			1.0	269.18 ± 38.63	1.95E-05 ± 2.80E-06	192.20 ± 7.58	
			1.5	50.75 ± 7.28	6.92E-07 ± 9.93E-08	6.83 ± 0.98	
UMTS(WCDMA/3G)	2110 - 2170	61	1.7	100.81 ± 14.47	2.73E-06 ± 3.92E-07	26.96 ± 3.87	**148.99 ± 21.24**
			2.0	**59.98 ± 21.04**	**9.67E-07 ± 1.39E-07**	**57.04 ± 8.18**	

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Table A16- Summary of Numerical results for Prempeh College

Band	Frequency (MHz)	Reference level (V/m)	Height (m)	Measured value (mV/m)	Exposure quotient	Power density (μW/m²)	Spatial Average (mV/m)
			1.0	138.85 ± 19.86	2.46E-05 ± 3.52E-06	51.14 ± 7.31	
			1.5	169.43 ± 24.23	3.66E-05 ± 5.23E-06	76.14 ± 10.89	
FM broadcast	87.5 - 108	28	1.7	164.98 ± 23.59	3.47E-05 ± 4.96E-06	72.20 ± 10.32	**151.97 ± 21.73**
			2.0	**131.07 ± 18.74**	**2.19E-05 ± 3.13E-06**	**45.57 ± 6.52**	
			1.0	8.92 ± 1.28	1.01E-07 ± 1.44E-08	0.21 ± 0.03	
			1.5	14.14 ± 2.02	2.55E-07 ± 3.65E-08	0.53 ± 0.08	
VHF TV	174 - 230	28	1.7	8.62 ± 1.23	9.48E-08 ± 1.36E-08	0.20 ± 0.03	**10.41 ± 1.49**
			2.0	**8.93 ± 1.28**	**1.02E-07 ± 1.46E-08**	**0.21 ± 0.03**	
			1.0	52.93 ± 7.57	3.11E-06 ± 4.45E-07	7.43 ± 1.06	
			1.5	46.73 ± 6.68	2.43E-06 ± 3.47E-07	5.79 ± 0.83	
UHF TV	470 - 862	30	1.7	50.08 ± 7.16	2.79E-06 ± 3.99E-07	6.65 ± 0.95	**54.47 ± 7.79**
			2.0	**66.13 ± 9.46**	**4.86E-06 ± 6.95E-07**	**11.60 ± 1.66**	
			1.0	231.03 ± 33.04	3.03E-05 ± 4.33E-06	141.58 ± 20.25	
			1.5	225.69 ± 32.27	2.89E-05± 4.13E-06	135.11 ± 19.32	
GSM 900	925 - 960	42	1.7	189.93 ± 27.16	2.04E-05 ± 2.92E-06	95.69 ± 13.68	**222.24 ± 31.78**
			2.0	**239.11 ± 34.19**	**3.24E-05 ± 4.63E-06**	**151.65 ± 21.69**	
			1.0	168.58 ± 24.11	8.45E-06 ± 1.21E-06	75.38 ± 10.78	
			1.5	174.943 ± 25.02	9.1E-06 ± 1.30E-06	81.18 ± 11.61	
GSM 1800	1805 - 1910	58	1.7	146.06 ± 20.89	6.34E-06 ± 9.07E-07	56.59 ± 8.09	**160.96 ± 23.02**
			2.0	**152.57 ± 21.82**	**6.92E-06 ± 9.90E-07**	**61.74 ± 8.83**	
			1.0	248.71 ± 35.57	1.66E-05 ± 2.37E-06	164.08 ± 23.46	
			1.5	212.20 ± 30.34	1.21E-05 ± 1.73E-06	119.44 ± 17.08	
UMTS (WCDMA/3G)	2110 - 2170	61	1.7	126.13 ± 18.04	4.28E-06 ± 6.12E-07	42.20 ± 6.03	**189.98 ± 27.17**
			2.0	**146.87 ± 21.00**	**5.80E-06 ± 8.29E-07**	**57.22 ± 8.18**	

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Table A17- Summary of Numerical Results for Airport-Aviance

Band	Frequency (MHz)	Reference level (V/m)	Height (m)	Measured value (mV/m)	Exposure quotient	Power density (µW/m²)	Spatial Average (mV/m)
FM broadcast	87.5 - 108	28	1.0	33.38 ± 4.72	1.42E-06 ± 2.01E-07	2.96 ± 0.42	50.53 ± 7.14
			1.5	39.42 ± 5.57	1.98E-06 ± 2.80E-07	4.12 ± 0.58	
			1.7	67.84 ± 9.59	5.87E-06 ± 8.30E-07	12.21 ± 1.73	
			2.0	**54.25 ± 7.67**	**3.75E-06 ± 5.31E-07**	**7.81 ± 1.10**	
VHF TV	174 - 230	28	1.0	5.64 ± 0.80	4.05E-08 ± 5.73E-09	0.08 ± 0.01	5.51 ± 0.78
			1.5	4.56 ± 0.64	2.65E-08 ± 3.75E-09	0.06 ± 0.01	
			1.7	6.81 ± 0.96	5.92E-08 ± 8.37E-09	0.12 ± 0.02	
			2.0	**4.75 ± 0.67**	**2.87E-08 ± 4.06E-09**	**0.06 ± 0.01**	
UHF TV	470 - 862	30	1.0	62.83 ± 8.88	4.39E-06 ± 6.20E-07	10.47 ± 1.48	84.66 ± 11.97
			1.5	75.77 ± 10.71	6.38E-06 ± 9.02E-07	15.23 ± 2.15	
			1.7	120.33 ± 17.01	1.61E-05 ± 2.27E-06	38.41 ± 5.43	
			2.0	**67.08 ± 9.49**	**5.00E-06 ± 7.07E-07**	**11.94 ± 1.69**	
GSM 900	925 - 960	42	1.0	405.77 ± 57.38	9.33E-05 ± 1.32E-05	436.74 ± 61.75	504.40 ± 71.27
			1.5	505.52 ± 71.48	1.45E-04 ± 2.05E-05	677.85 ± 95.85	
			1.7	440.82 ± 62.33	1.10E-04 ± 1.56E-05	515.44 ± 72.88	
			2.0	**634.94 ± 89.78**	**2.29E-04 ± 3.23E-05**	**1069.36 ± 151.21**	
GSM 1800	1805-1910	58	1.0	279.23 ± 39.48	2.32E-05 ± 3.28E-06	206.82 ± 29.24	281.41 ± 39.79
			1.5	286.28 ± 40.48	2.44E-05 ± 3.44E-06	217.39 ± 30.74	
			1.7	278.73 ± 39.41	2.31E-05 ± 3.27E-06	206.08 ± 29.14	
			2.0	**281.34 ± 39.78**	**2.35E-05 ± 3.33E-06**	**209.95 ± 29.69**	
UMTS (WCDMA/3G)	2110-2170	61	1.0	353.21 ± 49.94	3.35E-05 ± 4.74E-06	330.92 ± 46.79	339.07 ± 47.94
			1.5	319.44 ± 45.17	2.74E-05 ± 3.88E-06	270.67 ± 38.27	
			1.7	332.62 ± 47.03	2.97E-05 ± 4.20E-06	293.46 ± 41.50	
			2.0	**349.89 ± 49.47**	**3.29E-05 ± 4.65E-06**	**324.73 ± 45.92**	

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Table A18- Summary of Numerical Results for Rawlings Park

Band	Frequency (MHz)	Reference level (V/m)	Height (m)	Measured value (mV/m)	Exposure quotient	Power density (μW/m²)	Spatial average (mV/m)
			1.0	2.87 ± 0.41	1.05E-08 ± 1.50E-09	0.0220 ± 0.0031	
			1.5	3.07 ± 0.44	1.20E-08 ± 1.71E-09	0.0250 ± 0.0036	
FM broadcast	87.5 - 108	28	1.7	3.63 ± 0.52	1.68E-08 ± 2.39E-09	0.0350 ± 0.0050	3.14 ± 0.45
			2.0	**2.93 ± 0.42**	**1.09E-08 ± 1.55E-09**	**0.0230 ± 0.0032**	
			1.0	1.39 ± 0.20	2.49E-09 ± 3.55E-10	0.0051 ± 0.0007	
			1.5	1.17 ± 0.17	1.73E-09 ± 2.46E-10	0.0041 ± 0.0005	
VHF TV	174 - 230	28	1.7	0.53 ± 0.08	3.59E-10 ± 5.11E-11	0.0011 ± 0.0001	0.98 ± 0.14
			2.0	**0.49 ± 0.07**	**3.05E-10 ± 4.34E-11**	**0.0012 ± 0.0001**	
			1.0	32.25 ± 4.59	1.33E-06 ± 1.89E-07	2.7591 ± 0.3929	
			1.5	6.15 ± 0.88	4.82E-08 ± 6.86E-09	0.1002 ± 0.0143	
UHF TV	470 - 862	30	1.7	6.66 ± 0.95	5.66E-08 ± 8.06E-09	0.1181 ± 0.0168	16.91 ± 2.44
			2.0	**4.64 ± 0.66**	**2.74E-08 ± 3.90E-09**	**0.0572 ± 0.0081**	
			1.0	218.31 ± 31.09	6.08E-05 ± 8.66E-06	126.4171 ± 18.0018	
			1.5	367.18 ± 52.29	1.72E-04 ± 2.45E-05	357.6162 ± 50.9245	
GSM 900	925 - 960	42	1.7	295.11 ± 42.02	1.11E-04 ± 1.58E-05	231.0081 ± 32.8955	293.46 ± 41.79
			2.0	**273.67 ± 38.97**	**9.55E-05 ± 1.36E-05**	**198.6611 ± 28.2894**	
			1.0	185.49 ± 26.41	4.39E-05 ± 6.25E-06	91.2642 ± 12.9960	
			1.5	184.00 ± 26.20	4.32E-05 ± 6.15E-06	89.8042 ± 12.7880	
GSM 1800	1805-1910	58	1.7	204.97 ± 29.19	5.36E-05 ± 7.63E-06	111.4401 ± 15.8690	196.91 ± 28.04
			2.0	**211.70 ± 30.15**	**5.72E-05 ± 8.15E-06**	**118.8781 ± 16.9282**	
			1.0	413.85 ± 58.93	2.18E-04 ± 3.10E-05	454.3023 ± 64.6926	
			1.5	73.639 ± 10.49	6.92E-06 ± 9.85E-07	14.3841 ± 2.0483	
UMTS (WCDMA/3G)	2110 - 2170	61	1.7	120.41 ± 17.15	1.85E-05 ± 2.63E-06	38.4580 ± 5.4764	221.47 ± 31.54
			2.0	**70.68 ± 10.06**	**6.37E-06 ± 9.07E-07**	**13.2511 ± 1.8870**	

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Table A19- Summary of Numerical Results for Korle-Bu Teaching Hospital

Band	Frequency (MHz)	Reference level (V/m)	Height (m)	Measured value (mV/m)	Exposure quotient	Power density (µW/m²)	Spatial Average (mV/m)
			1.0	0.837 ± 0.121	8.93E-10 ± 1.25E-10	0.0019 ± 0.0003	
			1.5	0.961 ± 0.139	1.18E-09 ± 1.65E-10	0.0024 ± 0.0003	
FM broadcast	87.5 - 108	28	1.7	0.545 ± 0.079	3.78E-10 ± 5.29E-11	0.0008 ± 0.0001	**0.73 ± 0.10**
			2.0	**0.432 ± 0.062**	**2.38E-10 ± 3.33E-11**	**0.0005 ± 0.0001**	
			1.0	2.415 ± 0.348	7.44E-09 ± 1.04E-09	0.0155 ± 0.0022	
			1.5	2.476 ± 0.357	7.82E-09 ± 1.09E-09	0.0163 ± 0.0023	
VHF TV	174 - 230	28	1.7	2.540 ± 0.366	8.23E-09 ± 1.15E-09	0.0171 ± 0.0024	**2.33 ± 0.33**
			2.0	**1.832 ± 0.264**	**4.28E-09 ± 5.99E-10**	**0.0089 ± 0.0012**	
			1.0	9.656 ± 1.392	1.04E-07 ± 2.11E-08	0.2473 ± 0.0346	
			1.5	11.709 ± 1.688	1.52E-07 ± 2.03E-08	0.3637 ± 0.0509	
UHF TV	470 - 862	30	1.7	18.565 ± 2.677	3.83E-07 ± 5.36E-08	0.9142 ± 0.1280	**13.36 ± 1.87**
			2.0	**11.797 ± 1.701**	**1.55E-07 ± 2.17E-08**	**0.3691 ± 0.0517**	
			1.0	63.178 ± 9.110	2.26E-06 ± 3.16E-07	10.5874 ± 1.4822	
			1.5	95.628 ±13.790	5.18E-06 ± 7.25E-07	24.2565 ± 3.3959	
GSM 900	925 - 960	42	1.7	56.789 ± 8.189	1.83E-06 ± 2.56E-07	8.5544 ± 1.1976	**68.78 ± 9.63**
			2.0	**50.606 ± 7.297**	**1.45E-06 ± 2.03E-07**	**6.7930 ± 0.9510**	
			1.0	63.104 ± 9.100	1.18E-06 ± 1.65E-07	10.5626 ± 1.4788	
			1.5	62.410 ± 9.000	1.16E-06 ± 1.62E-07	10.3316 ± 1.4464	
GSM 1800	1805 - 1910	58	1.7	48.831 ± 7.041	7.09E-07 ± 9.93E-08	6.3248 ± 0.8855	**59.73 ± 8.36**
			2.0	**63.319 ± 9.131**	**1.19E-06 ± 1.67E-07**	**10.6347 ± 1.4889**	
			1.0	33.059 ± 4.767	2.94E-07 ± 4.12E-08	2.8989 ± 0.4059	
UMTS			1.5	31.114 ± 4.487	2.60E-07 ± 3.64E-08	2.5679 ± 0.3595	
(WCDMA/3G)	2110 - 2170	61	1.7	33.172 ± 4.783	2.96E-07 ± 4.14E-08	2.9188 ± 0.4086	**33.18 ± 4.64**
			2.0	**35.240 ± 5.081**	**3.34E-07 ± 4.68E-08**	**3.2941 ± 0.4612**	

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Table A20- Summary of Numerical Results for Tema Roundabout

Band	Frequency (MHz)	Reference level (V/m)	Height (m)	Measured value (mV/m)	Exposure quotient	Power density (μW/m²)	Spatial Average (mV/m)
			1.0	5.42 ± 0.78	3.74E-08 ± 5.35E-09	0.078 ± 0.011	
			1.5	23.51 ± 3.36	7.05E-07 ± 1.01E-07	1.466 ± 0.210	
FM broadcast	87.5 - 108	28	1.7	22.08 ± 3.16	6.22E-07 ± 8.89E-08	1.293 ± 0.181	**18.58 ± 2.66**
			2.0	**17.67 ± 2.53**	**3.98E-07 ± 5.69E-08**	**0.828 ± 0.121**	
			1.0	6.01 ± 0.86	4.59E-08 ± 6.57E-09	0.096 ± 0.012	
			1.5	5.24 ± 0.75	3.51E-08 ± 5.01E-09	0.073 ± 0.011	
VHF TV	174 - 230	28	1.7	6.86 ± 0.98	6.01E-08 ± 8.59E-09	0.125 ± 0.022	**5.83 ± 0.83**
			2.0	**5.02 ± 0.72**	**3.21E-08 ± 4.60E-09**	**0.067 ± 0.011**	
			1.0	80.49 ± 11.51	7.20E-06 ± 1.03E-06	17.185 ± 2.462	
			1.5	79.15 ± 11.32	6.96E-06 ± 9.95E-07	16.617 ± 2.381	
UHF TV	470 - 862	30	1.7	123.89 ± 17.72	1.71E-05 ± 2.44E-06	40.713 ± 5.820	**93.30 ± 13.34**
			2.0	**82.03 ± 11.73**	**7.48E-06 ± 1.07E-06**	**17.849 ± 2.551**	
			1.0	357.54 ± 51.13	7.25E-05 ± 1.04E-05	339.084 ± 48.491	
			1.5	384.02 ± 54.91	8.36E-05 ± 1.20E-05	391.171 ± 55.940	**363.81 ± 52.02**
GSM 900	925 - 960	42	1.7	338.01 ± 48.34	6.48E-05 ± 9.26E-06	303.052 ± 43.341	
			2.0	**374.01 ± 53.48**	**7.93E-05 ± 1.13E-05**	**371.044 ± 53.061**	
			1.0	311.35 ± 44.52	2.88E-05 ± 4.12E-06	257.132 ± 36.771	
			1.5	320.52 ± 45.83	3.05E-05 ± 4.37E-06	272.502 ± 38.970	
GSM 1800	1805-1910	58	1.7	316.46 ± 45.25	2.98E-05 ± 4.26E-06	265.642 ± 37.990	**320.92 ± 45.89**
			2.0	**334.88 ± 47.89**	**3.33E-05 ± 4.77E-06**	**297.466 ± 42.541**	
			1.0	178.57 ± 25.54	8.57E-06 ± 1.23E-06	84.582 ± 12.100	
			1.5	309.59 ± 44.27	2.58E-05 ± 3.68E-06	254.233 ± 36.361	
UMTS	2110 - 2170	61	1.7	114.33 ± 16.35	3.51E-06 ± 5.02E-07	34.672 ± 4.961	**197.51 ± 28.24**
(WCDMA/3G)			**2.0**	**123.46 ± 17.65**	**4.10E-06 ± 5.86E-07**	**40.431 ± 5.781**	

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Table A21- Summary of Numerical Results for Tema Community One

Band	Frequency (MHz)	Reference level (V/m)	Height (m)	Measured value (mV/m)	Exposure quotient	Power density ($\mu W/m^2$)	Spatial Average (mV/m)
			1.0	110.37 ± 15.78	1.55E-05 ± 2.22E-06	32.31 ± 4.62	
			1.5	165.11 ± 23.61	3.48E-05 ± 4.98E-06	72.31 ± 10.34	
FM broadcast	87.5 - 108	28	1.7	164.93 ± 23.58	3.47E-05 ± 4.96E-06	72.15 ± 10.32	**139.34 ± 19.93**
			2.0	**104.99 ± 15.01**	**1.41E-05 ± 2.02E-06**	**29.24 ± 4.18**	
			1.0	6.37 ± 0.91	5.18E-08 ± 7.41E-09	0.11 ± 0.02	
			1.5	5.08 ± 0.73	3.30E-08 ± 4.72E-09	0.07 ± 0.01	
VHF TV	174 - 230	28	1.7	7.16 ± 1.02	6.54E-08 ± 9.35E-09	0.14 ± 0.02	**6.01 ± 0.86**
			2.0	**5.16 ± 0.74**	**3.40E-08 ± 4.86E-09**	**0.07 ± 0.01**	
			1.0	66.49 ± 9.51	4.91E-06 ± 7.02E-07	11.73 ± 1.68	
			1.5	75.59 ± 10.81	6.35E-06 ± 9.08E-07	15.16 ± 2.17	
UHF TV	470 - 862	30	1.7	120.13 ± 17.18	1.60E-05 ± 2.29E-06	38.29 ± 5.47	**87.13 ± 12.46**
			2.0	**76.17 ± 10.89**	**6.45E-06 ± 9.22E-07**	**15.39 ± 2.20**	
			1.0	608.79 ± 87.06	2.10E-04 ± 3.00E-05	983.09 ± 140.58	
			1.5	405.47 ± 57.98	9.32E-05 ± 1.33E-05	436.09 ± 62.36	
GSM 900	925 - 960	42	1.7	680.22 ± 97.27	2.62E-04 ± 3.75E-05	1227.32 ± 175.51	**651.37 ± 93.15**
			2.0	**836.30 ± 119.59**	**3.96E-04 ± 5.66E-05**	**1855.17 ± 265.29**	
			1.0	313.39 ± 43.24	2.72E-05 ± 3.89E-06	242.55 ± 34.68	
			1.5	315.52 ± 45.83	3.05E-05 ± 4.36E-06	272.50 ± 38.97	
GSM 1800	1805-1910	58	1.7	246.45 ± 35.24	1.81E-05 ± 2.59E-06	161.11 ± 23.04	**290.34 ± 41.2**
			2.0	**321.73 ± 46.01**	**3.08E-05 ± 4.40E-06**	**274.56 ± 39.26**	
			1.0	413.85 ± 59.18	4.60E-05 ± 6.58E-06	454.30 ± 64.97	
			1.5	870.02 ± 124.41	2.03E-04 ± 2.90E-05	2007.79 ± 287.11	
UMTS	2110 - 2170	61	1.7	906.12 ± 129.58	2.21E-04 ± 3.16E-05	2177.86 ± 311.43	**790.65 ± 113.06**
(WCDMA/3G)			**2.0**	**866.74 ± 123.94**	**2.02E-04 ± 2.89E-05**	**1992.67 ± 284.95**	

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Table A22- Summary of Numerical Results for University of Ghana

Band	Frequency (MHz)	Reference level (V/m)	Height (m)	Measured value (mV/m)	Exposure quotient	Power density (μW/m²)	Spatial average (mV/m)
			1.0	98.89 ± 14.14	1.25E-05 ± 1.79E-06	25.94 ± 3.72	
			1.5	607.24 ± 86.84	4.70E-04 ± 6.74E-05	978.09 ± 140.26	
FM broadcast	87.5 - 108	28	1.7	607.19 ± 86.83	4.70E-04 ± 6.74E-05	977.93 ± 140.24	**476.79 ± 68.18**
			2.0	**402.65 ± 57.58**	**2.07E-04 ± 2.97E-05**	**430.04 ± 61.67**	
			1.0	6.06 ± 0.87	4.68E-08 ± 6.71E-09	0.09 ± 0.01	
			1.5	5.08 ± 0.73	3.30E-08 ± 4.73E-09	0.06 ± 0.01	
VHF TV	174 - 230	28	1.7	7.16 ± 1.02	6.54E-08 ± 9.38E-09	0.13 ± 0.02	**5.93 ± 0.85**
			2.0	**5.16 ± 0.74**	**3.40E-08 ± 4.88E-09**	**0.07 ± 0.01**	
			1.0	62.23 ± 8.90	4.30E-06 ± 6.17E-07	10.27 ± 1.47	
			1.5	75.59 ± 10.81	6.35E-06 ± 9.11E-07	15.15 ± 2.17	
UHF TV	470 - 862	30	1.7	120.13 ± 17.18	1.60E-05 ± 2.29E-06	38.27 ± 5.49	**86.34 ± 12.35**
			2.0	**76.17 ± 10.89**	**6.45E-06 ± 9.25E-07**	**15.39 ± 2.21**	
			1.0	549.75 ± 78.61	1.71E-04 ± 2.45E-05	801.65 ± 114.96	
			1.5	405.47 ± 57.98	9.32E-05 ± 1.34E-05	436.09 ± 62.54	
GSM 900	925 - 960	42	1.7	680.22 ± 97.27	2.62E-04 ± 3.76E-05	1227.31 ± 176.00	**638.11 ± 91.25**
			2.0	**836.30 ± 119.59**	**3.96E-04 ± 5.68E-05**	**1855.16 ± 266.03**	
			1.0	302.35 ± 43.24	2.72E-05 ± 3.90E-06	242.48 ± 34.77	
			1.5	320.52 ± 45.83	3.05E-05 ± 4.37E-06	272.50 ± 39.08	
GSM 1800	1805-1910	58	1.7	246.46 ± 35.24	1.81E-05 ± 2.60E-06	161.12 ± 23.10	**299.33 ± 42.80**
			2.0	**321.74 ± 46.01**	**3.08E-05 ± 4.42E-06**	**274.58 ± 39.37**	
			1.0	925.54 ± 132.35	2.30E-04 ± 3.30E-05	2272.21 ± 325.84	
			1.5	870.02 ± 124.41	2.03E-04 ± 2.91E-05	2007.78 ± 287.92	
UMTS (WCDMA/3G)	2110 - 2170	61	1.7	906.12 ± 129.58	2.21E-04 ± 3.17E-05	2177.86 ± 312.31	**892.44 ± 127.62**
			2.0	**866.74 ± 123.94**	**2.02E-04 ± 2.90E-05**	**1992.67 ± 285.75**	

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Table A23- Summary of Numerical Results for Abeka Junction

Band	Frequency (MHz)	Reference level (V/m)	Height (m)	Measured value (mV/m)	Exposure quotient	Power density (μW/m²)	Spatial average (mV/m)
			1.0	70.74 ± 10.12	6.38E-06 ±9.12E-07	13.27 ± 1.90	
			1.5	87.52 ± 12.52	9.78E-06 ±1.40E-06	20.32 ± 2.91	
FM broadcast	87.5 - 108	28	1.7	56.74 ± 8.11	4.11E-06 ±5.88E-07	8.54 ± 1.22	**72.27 ± 10.36**
			2.0	70.73 ± 10.11	6.38E-06 ±9.12E-07	13.27 ± 1.90	
			1.0	6.06 ± 0.87	4.68E-08 ±6.69E-09	0.10 ± 0.01	
			1.5	5.08 ± 0.73	3.30E-08 ±4.72E-09	0.07 ± 0.01	
VHF TV	174 - 230	28	1.7	7.15 ± 1.02	6.51E-08 ±9.31E-09	0.14 ± 0.02	**5.89 ± 0.84**
			2.0	5.06 ± 0.72	3.26E-08 ±4.66E-09	0.07 ± 0.01	
			1.0	62.22 ± 8.90	4.30E-06 ±6.15E-07	10.27 ± 1.47	
			1.5	75.59 ± 10.81	6.35E-06 ±9.08E-07	15.16 ± 2.17	
UHF TV	470 - 862	30	1.7	120.13 ± 17.18	1.60E-05 ±2.29E-06	38.28 ± 5.47	**86.35 ± 12.38**
			2.0	76.20 ± 10.90	6.45E-06 ±9.22E-07	15.40 ± 2.20	
			1.0	280.25 ± 40.08	4.45E-05 ±6.36E-06	208.33 ± 29.79	
			1.5	326.20 ± 46.65	6.03E-05 ±8.62E-06	282.25 ± 40.36	
GSM 900	925 - 960	42	1.7	326.86 ± 46.74	6.06E-05 ±8.67E-06	283.39 ± 40.52	**313.02 ± 44.89**
			2.0	316.45 ± 45.25	5.68E-05 ±8.12E-06	265.62 ± 37.98	
			1.0	260.79 ± 37.29	2.02E-05 ±2.89E-06	180.40 ± 25.80	
			1.5	285.80 ± 40.87	2.43E-05 ±3.47E-06	216.66 ± 30.98	
GSM 1800	1805 - 1910	58	1.7	241.34 ± 34.51	1.73E-05 ±2.47E-06	154.50 ± 22.09	**262.15 ± 37.59**
			2.0	258.75 ± 37.00	1.99E-05 ±2.85E-06	177.59 ± 25.40	
			1.0	414.01 ± 59.20	4.60E-05 ±6.58E-06	454.65 ± 65.02	
			1.5	151.10 ± 21.61	2.14E-06 ±3.06E-07	60.56 ± 8.66	
UMTS(WCDMA/3G)	2110 - 2170	61	1.7	188.01 ± 26.89	9.50E-06 ±1.36E-06	93.76 ± 13.41	**242.14 ± 34.72**
			2.0	141.23 ± 20.20	5.36E-06 ±7.66E-07	52.91 ± 7.57	

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Table A24- Summary of Numerical Results for Comet Hills

Band	Frequency (MHz)	Reference level (V/m)	Height (m)	Measured value (mV/m)	Exposure quotient	Power density (μW/m²)	Spatial Average (mV/m)
			1.0	5.24 ± 0.73	1.87E-04 ± 2.62E-05	0.073 ± 0.010	
			1.5	3.44 ± 0.48	1.23E-04 ± 1.72E-05	0.031 ± 0.004	
FM broadcast	87.5- 108	28	1.7	2.16 ± 0.30	7.71E-05 ± 1.08E-05	0.012 ± 0.002	**3.45 ± 0.48**
			2.0	**1.94 ± 0.27**	**6.93E-05 ± 9.70E-06**	**0.010 ± 0.001**	
			1.0	4.12 ± 0.58	1.47E-04 ± 2.06E-05	0.045 ± 0.006	
			1.5	3.85 ± 0.54	1.38E-04 ± 1.93E-05	0.039 ± 0.006	
HF TV	174 - 230	28	1.7	4.89 ± 0.68	1.75E-04 ± 2.45E-05	0.063 ± 0.009	**4.03 ± 0.56**
			2.0	**3.02 ± 0.42**	**1.08E-04 ± 1.51E-05**	**0.024 ± 0.003**	
			1.0	1.79 ± 0.25	5.97E-05 ± 8.35E-06	0.008 ± 0.001	
			1.5	1.49 ± 0.21	4.97E-05 ± 6.95E-06	0.006 ± 0.001	
UHF TV	470 - 862	30	1.7	1.73 ± 0.24	5.77E-05 ± 8.07E-06	0.008 ± 0.001	**1.70 ± 0.24**
			2.0	**1.77 ± 0.25**	**5.90E-05 ± 8.26E-06**	**0.008 ± 0.001**	
			1.0	2.86 ± 0.40	6.81E-05 ± 9.53E-06	0.022 ± 0.003	
			1.5	1.21 ± 0.17	2.88E-05 ± 4.03E-06	0.004 ± 0.001	
GSM 900	925 - 960	42	1.7	8.51 ± 1.19	2.03E-04 ± 2.84E-05	0.192 ± 0.027	**5.91 ± 0.83**
			2.0	**7.59 ± 1.06**	**1.81E-04 ± 2.53E-05**	**0.153 ± 0.021**	
			1.0	6.72 ± 0.94	1.16E-04 ± 1.62E-05	0.120 ± 0.017	
			1.5	3.07 ± 0.43	5.29E-05 ± 7.41E-06	0.025 ± 0.003	
GSM 1800	1805-1910	58	1.7	4.62 ± 0.65	7.97E-05 ± 1.12E-05	0.057 ± 0.008	**5.08 ± 0.71**
			2.0	**5.23 ± 0.73**	**9.02E-05 ± 1.26E-05**	**0.073 ± 0.010**	
			1.0	5.64 ± 0.79	9.25E-05 ± 1.29E-05	0.084 ± 0.012	
			1.5	4.79 ± 0.67	7.85E-05 ± 1.10E-05	0.061 ± 0.009	
UMTS	110-2170	61	1.7	5.56 ± 0.78	9.11E-05 ± 1.28E-05	0.082 ± 0.011	**5.24 ± 0.73**
(WCDMA/3G)			**2.0**	**4.92 ± 0.69**	**8.07E-05 ± 1.13E-05**	**0.064 ± 0.009**	

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Table A25- Summary of Numerical Results for McCarty Hill

Band	Frequency (MHz)	Reference level (V/m)	Height (m)	Measured value (mV/m)	Exposure quotient	Power density (μW/m²)	Spatial Average (mV/m)
			1.0	114.46 ± 16.14	1.67E-05 ± 2.35E-06	34.75 ± 4.90	
			1.5	159.62 ± 22.51	3.25E-05 ± 4.58E-06	67.58 ± 9.53	
FM broadcast	87.5 - 108	28	1.7	147.66 ± 20.82	2.78E-05 ± 3.92E-06	57.83 ± 8.15	**138.89 ± 19.58**
			2.0	**129.53 ± 18.26**	**2.14E-05 ± 3.02E-06**	**44.50 ± 6.28**	
			1.0	5.78 ± 0.81	4.26E-08 ± 6.01E-09	0.09 ± 0.01	
			1.5	5.16 ± 0.73	3.40E-08 ± 4.79E-09	0.07 ± 0.01	
VHF TV	174 - 230	28	1.7	7.16 ± 1.01	6.54E-08 ± 9.22E-09	0.14 ± 0.02	**5.87 ± 0.83**
			2.0	**5.16 ± 0.73**	**3.40E-08 ± 4.79E-09**	**0.07 ± 0.01**	
			1.0	47.90 ± 6.75	2.93E-06 ± 4.13E-07	6.09 ± 0.86	
			1.5	24.94 ± 3.52	7.93E-07 ± 1.12E-07	1.65 ± 0.23	
UHF TV	470 - 862	30	1.7	23.04 ± 3.25	6.77E-07 ± 9.55E-08	1.41 ± 0.20	**31.89 ± 4.50**
			2.0	**24.94 ± 3.52**	**7.93E-07 ± 1.12E-07**	**1.65 ± 0.23**	
			1.0	574.07 ± 80.94	4.20E-04 ± 5.92E-05	874.15 ± 123.26	
			1.5	528.95 ± 74.58	3.57E-04 ± 5.03E-05	742.14 ± 104.64	
GSM 900	925 - 960	42	1.7	549.69 ± 77.51	3.85E-04 ± 5.43E-05	801.48 ± 113.01	**545.73 ± 76.95**
			2.0	**528.95 ± 74.58**	**3.57E-04 ± 5.03E-05**	**742.14 ± 104.64**	
			1.0	305.86 ± 43.13	1.19E-04 ± 1.68E-05	248.14 ± 34.99	
			1.5	310.03 ± 43.71	1.23E-04 ± 1.73E-05	254.96 ± 35.95	
GSM 1800	1805 - 1910	58	1.7	300.93 ± 42.43	1.16E-04 ± 1.64E-05	240.21 ± 33.87	**306.80 ± 43.26**
			2.0	**310.29 ± 43.75**	**1.23E-04 ± 1.73E-05**	**255.38 ± 36.01**	
			1.0	413.85 ± 58.35	2.18E-04 ± 3.07E-05	454.30 ± 64.06	
			1.5	223.12 ± 31.46	6.18E-05 ± 8.71E-06	132.05 ± 18.62	
UMTS(WCDMA/3G)	2110 - 2170	61	1.7	162.89 ± 22.97	3.38E-05 ± 4.77E-06	70.38 ± 9.92	**271.46 ± 38.28**
			2.0	**220.18 ± 31.05**	**6.18E-05 ± 8.71E-06**	**128.59 ± 18.13**	

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Table A26- Summary of Numerical Results for Sakumono Total Filling Station

Band	Frequency (MHz)	Reference level (V/m)	Height (m)	Measured value (V/m)	Exposure quotient	Power density (µW/m²)	Spatial average (mV/m)
			1.0	91.81 ± 12.95	1.07E-05 ± 1.51E-06	22.36 ± 3.15	
			1.5	165.11 ± 23.28	3.47E-05 ± 4.89E-06	72.31 ± 10.20	
FM broadcast	87.5 - 108	28	1.7	164.93 ± 23.26	3.47E-05 ± 4.89E-06	72.15 ± 10.17	**139.07 ± 19.61**
			2.0	**120.31 ± 16.96**	**1.85E-05 ± 2.61E-06**	**38.39 ± 5.41**	
			1.0	6.06 ± 0.85	4.68E-08 ± 6.60E-09	0.10 ± 0.01	
			1.5	5.08 ± 0.72	3.29E-08 ± 4.64E-09	0.07 ± 0.01	
VHF TV	174 - 230	28	1.7	7.16 ± 1.01	6.54E-08 ± 9.22E-09	0.14 ± 0.02	**5.93 ± 0.84**
			2.0	**5.16 ± 0.73**	**3.39E-08 ± 4.78E-09**	**0.07 ± 0.01**	
			1.0	65.43 ± 9.23	4.76E-06 ± 6.71E-07	11.36 ± 1.60	
			1.5	65.59 ± 9.25	4.78E-06 ± 6.74E-07	11.41 ± 1.61	
UHF TV	470 - 862	30	1.7	64.52 ± 9.10	4.62E-06 ± 6.51E-07	11.04 ± 1.56	**65.42 ± 9.22**
			2.0	**66.17 ± 9.33**	**4.87E-06 ± 6.87E-07**	**11.61 ± 1.64**	
			1.0	229.68 ± 32.38	2.99E-05 ± 4.22E-06	139.93 ± 19.73	
			1.5	403.97 ± 56.96	9.25E-05 ± 1.30E-05	432.87 ± 61.03	
GSM 900	925 - 960	42	1.7	308.43 ± 43.49	5.39E-05 ± 7.60E-06	252.33 ± 35.58	**318.52 ± 44.91**
			2.0	**307.83 ± 43.40**	**5.37E-05 ± 7.57E-06**	**251.35 ± 35.44**	
			1.0	271.84 ± 38.33	2.19E-05 ± 3.09E-06	196.01 ± 27.64	
			1.5	268.02 ± 37.79	2.14E-05 ± 3.02E-06	190.54 ± 26.87	
GSM 1800	1805-1910	58	1.7	257.53 ± 36.31	1.97E-05 ± 2.78E-06	175.92 ± 24.80	**266.51 ± 37.58**
			2.0	**268.43 ± 37.85**	**2.14E-05 ± 3.02E-06**	**191.13 ± 26.95**	
			1.0	413.85 ± 58.35	4.60E-05 ± 6.49E-06	454.30 ± 64.06	
			1.5	258.31 ± 36.42	1.81E-05 ± 2.55E-06	176.99 ± 24.96	
UMTS(WCDMA/3G)	2110-2170	61	1.7	263.61 ± 37.17	1.87E-05 ± 2.64E-06	184.32 ± 25.99	**226.35 ± 31.92**
			2.0	**259.76 ± 36.63**	**1.81E-05 ± 2.55E-06**	**178.98 ± 25.24**	

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Table A26- Summary of Numerical Results for Sakumono Total Filling Station

Band	Frequency (MHz)	Reference level (V/m)	Height (m)	Measured value (V/m)	Exposure quotient	Power density (μW/m²)	Spatial average (mV/m)
			1.0	91.81 ± 12.95	1.07E-05 ± 1.51E-06	22.36 ± 3.15	
			1.5	165.11 ± 23.28	3.47E-05 ± 4.89E-06	72.31 ± 10.20	
FM broadcast	87.5 - 108	28	1.7	164.93 ± 23.26	3.47E-05 ± 4.89E-06	72.15 ± 10.17	**139.07 ± 19.61**
			2.0	**120.31 ± 16.96**	**1.85E-05 ± 2.61E-06**	**38.39 ± 5.41**	
			1.0	6.06 ± 0.85	4.68E-08 ± 6.60E-09	0.10 ± 0.01	
			1.5	5.08 ± 0.72	3.29E-08 ± 4.64E-09	0.07 ± 0.01	
VHF TV	174 - 230	28	1.7	7.16 ± 1.01	6.54E-08 ± 9.22E-09	0.14 ± 0.02	**5.93 ± 0.84**
			2.0	**5.16 ± 0.73**	**3.39E-08 ± 4.78E-09**	**0.07 ± 0.01**	
			1.0	65.43 ± 9.23	4.76E-06 ± 6.71E-07	11.36 ± 1.60	
			1.5	65.59 ± 9.25	4.78E-06 ± 6.74E-07	11.41 ± 1.61	
UHF TV	470 - 862	30	1.7	64.52 ± 9.10	4.62E-06 ± 6.51E-07	11.04 ± 1.56	**65.42 ± 9.22**
			2.0	**66.17 ± 9.33**	**4.87E-06 ± 6.87E-07**	**11.61 ± 1.64**	
			1.0	229.68 ± 32.38	2.99E-05 ± 4.22E-06	139.93 ± 19.73	
			1.5	403.97 ± 56.96	9.25E-05 ± 1.30E-05	432.87 ± 61.03	
GSM 900	925 - 960	42	1.7	308.43 ± 43.49	5.39E-05 ± 7.60E-06	252.33 ± 35.58	**318.52 ± 44.91**
			2.0	**307.83 ± 43.40**	**5.37E-05 ± 7.57E-06**	**251.35 ± 35.44**	
			1.0	271.84 ± 38.33	2.19E-05 ± 3.09E-06	196.01 ± 27.64	
			1.5	268.02 ± 37.79	2.14E-05 ± 3.02E-06	190.54 ± 26.87	
GSM 1800	1805-1910	58	1.7	257.53 ± 36.31	1.97E-05 ± 2.78E-06	175.92 ± 24.80	**266.51 ± 37.58**
			2.0	**268.43 ± 37.85**	**2.14E-05 ± 3.02E-06**	**191.13 ± 26.95**	
			1.0	413.85 ± 58.35	4.60E-05 ± 6.49E-06	454.30 ± 64.06	
			1.5	258.31 ± 36.42	1.81E-05 ± 2.55E-06	176.99 ± 24.96	
UMTS(WCDMA/3G)	2110-2170	61	1.7	263.61 ± 37.17	1.87E-05 ± 2.64E-06	184.32 ± 25.99	**226.35 ± 31.92**
			2.0	**259.76 ± 36.63**	**1.81E-05 ± 2.55E-06**	**178.98 ± 25.24**	

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Table A27- Summary of Numerical Results for Vienna City Roundabout

Band	Frequency (MHz)	Reference level (V/m)	Height (m)	Measured value (mV/m)	Exposure quotient	Power density (µW/m²)	spatial average (mV/m)
			1.0	69.71 ± 9.83	6.20E-06 ± 8.74E-07	12.891 ± 1.8175	
			1.5	57.12 ± 8.05	4.16E-06 ± 5.87E-07	8.6524 ± 1.2203	
FM broadcast	87.5 - 108	28	1.7	54.69 ± 7.71	3.81E-06 ± 5.37E-07	7.9304 ± 1.1186	**56.88 ± 8.02**
			2.0	**42.78 ± 6.03**	**2.33E-06 ± 3.29E-07**	**4.8540 ± 0.6845**	
			1.0	1.09 ± 0.15	1.50E-09 ± 2.12E-10	0.0031 ± 0.0004	
			1.5	1.12 ± 0.16	1.60E-09 ± 2.26E-10	0.0032 ± 0.0005	
VHF TV	174 - 230	28	1.7	2.57 ± 0.36	8.39E-09 ± 1.18E-09	0.0181 ± 0.0025	**1.72 ± 0.24**
			2.0	**1.69 ± 0.24**	**3.68E-09 ± 5.19E-10**	**0.0080 ± 0.0011**	
			1.0	6.65 ± 0.94	4.91E-08 ± 6.92E-09	0.1171 ± 0.0165	
			1.5	12.59 ± 1.78	1.76E-07 ± 2.48E-08	0.4201 ± 0.0593	
UHF TV	470 - 862	30	1.7	16.37 ± 2.31	2.98E-07 ± 4.20E-08	0.7111 ± 0.1002	**16.59 ± 2.34**
			2.0	**25.12 ± 3.54**	**7.01E-07 ± 9.88E-08**	**1.6741 ± 0.2360**	
			1.0	130.36 ± 18.38	9.63E-06 ± 1.36E-06	45.0761 ± 6.3557	
			1.5	134.08 ± 18.91	1.02E-05 ± 1.44E-06	47.6860 ± 6.7237	
GSM 900	925 - 960	42	1.7	138.32 ± 19.50	1.08E-05 ± 1.52E-06	50.7492 ± 7.1556	**133.73 ± 18.86**
			2.0	**132.04 ± 18.62**	**9.88E-06 ± 1.39E-06**	**46.2460 ± 6.5206**	
			1.0	96.41 ± 13.59	2.76E-06 ± 3.89E-07	24.6551 ± 3.4763	
			1.5	86.57 ± 12.21	2.23E-06 ± 3.14E-07	19.8792 ± 2.8029	
GSM 1800	1805-1910	58	1.7	73.98 ± 10.43	1.63E-06 ± 2.30E-07	14.5170 ± 2.0469	**83.84 ± 11.82**
			2.0	**76.57 ± 10.80**	**1.74E-06 ± 2.45E-07**	**15.5520 ± 2.1928**	
			1.0	13.18 ± 1.86	4.67E-06 ± 6.58E-07	0.46110 ± 0.0650	
			1.5	116.75 ± 16.46	3.66E-06 ± 5.16E-07	36.1552 ± 5.0979	
UMTS(WCDMA/3G)	2110-2170	61	1.7	115.57 ± 16.30	3.59E-06 ± 5.06E-07	35.4281 ± 4.9954	**120.04 ± 16.93**
			2.0	**115.19 ± 16.24**	**3.57E-06 ± 5.03E-07**	**35.1961 ± 4.9626**	

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Table A28- Summary of Numerical Results for Takoradi Technical University

Band	Frequency (MHz)	Reference level (V/m)	Height (m)	Measured value (mV/m)	Exposure quotient	Power density (μW/m²)	Spatial average (mV/m)
FM broadcast	87.5 - 108	28	1.0	59.57 ± 8.42	4.53E-06 ± 6.41E-07	9.421 ± 1.331	**41.07 ± 5.81**
			1.5	50.26 ± 7.09	3.22E-06 ± 4.54E-07	6.707 ± 0.944	
			1.7	24.07 ± 3.39	7.39E-07 ± 1.04E-07	1.544 ± 0.216	
			2.0	**9.65 ± 1.36**	**1.19E-07 ± 1.68E-08**	**0.255 ± 0.034**	
VHF TV	174 - 230	28	1.0	2.24 ± 0.32	6.40E-09 ± 9.02E-10	0.011 ± 0.001	**3.01 ± 0.43**
			1.5	3.78 ± 0.53	1.82E-08 ± 2.57E-09	0.044 ± 0.005	
			1.7	2.87 ± 0.40	1.05E-08 ± 1.48E-09	0.012 ± 0.003	
			2.0	**2.97 ± 0.42**	**1.12E-08 ± 1.58E-09**	**0.012 ± 0.003**	
UHF TV	470 - 862	30	1.0	26.73 ± 3.77	7.94E-07 ± 1.12E-07	1.900 ± 0.267	**25.49 ± 3.60**
			1.5	21.41 ± 3.02	5.09E-07 ± 7.18E-08	1.222 ± 0.171	
			1.7	24.26 ± 3.42	6.54E-07 ± 9.22E-08	1.556 ± 0.220	
			2.0	**28.92 ± 4.08**	**9.30E-07 ± 1.31E-07**	**2.232 ± 0.312**	
GSM 900	925 - 960	42	1.0	110.36 ± 15.56	6.90E-06 ± 9.73E-07	32.311 ± 4.555	**120.96 ± 17.10**
			1.5	124.08 ± 17.50	8.73E-06 ± 1.23E-06	40.814 ± 5.758	
			1.7	128.32 ± 18.09	9.33E-06 ± 1.32E-06	43.618 ± 6.158	
			2.0	**120.36 ± 16.97**	**8.21E-06 ± 1.16E-06**	**38.413 ± 5.418**	
GSM 1800	1805-1910	58	1.0	94.55 ± 13.33	2.66E-06 ± 3.75E-07	23.711 ± 3.343	**95.01 ± 13.43**
			1.5	98.05 ± 13.83	2.86E-06 ± 4.03E-07	25.510 ± 3.595	
			1.7	99.72 ± 14.06	2.96E-06 ± 4.17E-07	26.318 ± 3.719	
			2.0	**87.23 ± 12.30**	**2.26E-06 ± 3.19E-07**	**20.118 ± 2.845**	
UMTS(WCDMA/3G)	2110-2170	61	1.0	231.85 ± 32.69	1.44E-05 ± 2.03E-06	142.518 ± 20.104	**140.05 ± 19.80**
			1.5	78.57 ± 11.08	1.66E-06 ± 2.34E-07	16.317 ± 2.308	
			1.7	85.37 ± 12.04	1.96E-06 ± 2.76E-07	19.313 ± 2.725	
			2.0	**106.05 ± 14.95**	**3.02E-06 ± 4.26E-07**	**29.813 ± 4.206**	

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Table A29- Summary of Numerical Results for Anaji West Line

Band	Frequency (MHz)	Reference level (V/m)	Height (m)	Measured value (mV/m)	Exposure quotient	Power density (μW/m²)	Spatial Average (mV/m)
			1.0	68.24 ± 9.66	5.94E-06 ± 8.41E-07	12.350 ± 1.749	
			1.5	60.15 ± 8.52	4.62E-06 ± 6.54E-07	9.601 ± 1.359	
FM broadcast	87.5 - 108	28	1.7	50.25 ± 7.12	3.22E-06 ± 4.56E-07	6.700 ± 0.948	**60.84 ± 8.61**
			2.0	**63.28 ± 8.96**	**5.11E-06 ± 7.24E-07**	**10.621 ± 1.504**	
			1.0	2.24 ± 0.32	6.40E-09 ± 9.06E-10	0.012 ± 0.002	
			1.5	5.78 ± 0.82	4.26E-08 ± 6.03E-09	0.091 ± 0.013	
VHF TV	174 - 230	28	1.7	2.57 ± 0.36	8.39E-09 ± 1.19E-09	0.023 ± 0.003	**3.67 ± 0.52**
			2.0	**2.97 ± 0.42**	**1.12E-08 ± 1.59E-09**	**0.021 ± 0.003**	
			1.0	26.73 ± 3.78	7.94E-07 ± 1.12E-07	1.901 ± 0.268	
			1.5	21.41 ± 3.03	5.09E-07 ± 7.21E-08	1.220 ± 0.172	
UHF TV	470 - 862	30	1.7	24.26 ± 3.44	6.54E-07 ± 9.26E-08	1.561 ± 0.221	**25.49 ± 3.61**
			2.0	**28.92 ± 4.10**	**9.30E-07 ± 1.32E-07**	**2.221 ± 0.314**	
			1.0	200.39 ± 28.38	2.28E-05 ± 3.23E-06	106.512 ± 15.083	
			1.5	237.85 ± 33.68	3.21E-05 ± 4.55E-06	150.061 ± 21.249	
GSM 900	925 - 960	42	1.7	275.46 ± 39.01	4.30E-05 ± 6.09E-06	201.270 ± 28.499	**287.47 ± 40.71**
			2.0	**397.44 ± 56.28**	**8.95E-05 ± 1.27E-05**	**418.991 ± 59.329**	
			1.0	246.37 ± 34.89	1.80E-05 ± 2.55E-06	161.002 ± 22.798	
			1.5	231.63 ± 32.80	1.59E-05 ± 2.25E-06	142.311 ± 20.152	
GSM 1800	1805-1910	58	1.7	230.83 ± 32.69	1.58E-05 ± 2.24E-06	141.333 ± 20.013	**244.47 ± 34.62**
			2.0	**267.28 ± 37.85**	**2.12E-05 ± 3.00E-06**	**189.492 ± 26.832**	
			1.0	322.78 ± 45.71	2.80E-05 ± 3.96E-06	276.362 ± 39.132	
			1.5	85.46 ± 12.10	1.96E-06 ± 2.78E-07	19.373 ± 2.743	
UMTS(WCDMA/3G)	2110-2170	61	1.7	169.07 ± 23.94	7.68E-06 ± 1.09E-06	75.822 ± 10.730	**187.13 ± 26.50**
			2.0	**121.94 ± 17.27**	**4.00E-06 ± 5.66E-07**	**39.441 ± 5.561**	

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Table A30- Summary of Numerical Results for Galaxy Aben Be Bong

Band	Frequency (MHz)	Reference level (V/m)	Height (m)	Measured value (mV/m)	Exposure quotient	Power density (μW/m²)	Spatial Average (mV/m)
			1.0	33.96 ± 4.80	1.47E-06 ± 8.40E-07	3.061 ± 0.433	
			1.5	32.52 ± 4.60	1.35E-06 ± 6.53E-07	2.812 ± 0.397	
FM broadcast	87.5 - 108	28	1.7	39.75 ± 5.62	2.02E-06 ± 4.55E-07	4.191 ± 0.593	**35.13 ± 4.97**
			2.0	**33.84 ± 4.78**	**1.46E-06 ± 7.23E-07**	**3.042 ± 0.430**	
			1.0	2.23 ± 0.32	6.4E-09 ± 9.05E-10	0.011 ± 0.002	
			1.5	2.78 ± 0.39	9.85E-09 ± 6.02E-09	0.022 ± 0.003	
VHF TV	174 - 230	28	1.7	2.57 ± 0.36	8.39E-09 ± 1.19E-09	0.023 ± 0.002	**2.65 ± 0.37**
			2.0	**2.97 ± 0.42**	**1.12E-08 ± 1.58E-09**	**0.022 ± 0.003**	
			1.0	26.72 ± 3.78	7.93E-07 ± 1.12E-07	1.891 ± 0.268	
			1.5	21.39 ± 3.02	5.09E-07 ± 7.20E-08	1.210 ± 0.172	
UHF TV	470 - 862	30	1.7	24.16 ± 3.42	6.49E-07 ± 9.25E-08	1.551 ± 0.219	**25.39 ± 3.59**
			2.0	**28.68 ± 4.06**	**9.14E-07 ± 1.32E-07**	**2.181 ± 0.309**	
			1.0	110.11 ± 15.57	6.87E-06 ± 3.22E-06	32.162 ± 4.547	
			1.5	120.16 ± 17.54	8.72E-06 ± 4.54E-06	38.891 ± 5.345	
SM 900	925 - 960	42	1.7	157.54 ± 22.28	1.41E-05 ± 6.08E-06	65.830 ± 9.309	**135.82 ± 19.20**
			2.0	**146.49 ± 20.71**	**1.22E-05 ± 1.27E-05**	**56.921 ± 8.049**	
			1.0	104.55 ± 14.78	3.25E-06 ± 2.55E-06	28.991 ± 4.100	
			1.5	98.05 ± 13.86	2.86E-06 ± 2.25E-06	25.500 ± 3.606	
GSM 1800	1805-1910	58	1.7	99.72 ± 14.10	2.96E-06 ± 2.23E-06	26.381 ± 3.730	**97.59 ± 13.80**
			2.0	**87.23 ± 12.33**	**2.26E-06 ± 3.00E-06**	**20.181 ± 2.854**	
			1.0	331.85 ± 46.92	2.96E-05 ± 3.96E-06	292.111 ± 41.30	
			1.5	78.57 ± 11.11	1.66E-06 ± 2.77E-07	16.371 ± 2.315	
UMTS(WCDMA/3G)	2110-2170	61	1.7	85.37 ± 12.07	1.96E-06 ± 1.09E-06	19.331 ± 2.733	**183.59 ± 25.96**
			2.0	**106.05 ± 15.00**	**3.02E-06 ± 5.66E-07**	**29.831 ± 4.218**	

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Table A31- Summary of Numerical Results for Lagos Town

Band	Frequency (MHz)	Reference level (V/m)	Height (m)	Measured value (mV/m)	Exposure quotient	Power density (μW/m²)	Spatial Average (mV/m)
FM broadcast	87.5 - 108	28	1.0	39.25 ± 5.55	1.97E-06 ± 8.41E-07	4.091 ± 0.578	**36.49 ± 5.16**
			1.5	34.12 ± 4.83	1.48E-06 ± 6.54E-07	3.091 ± 0.437	
			1.7	30.53 ± 4.32	1.19E-06 ± 4.56E-07	2.472 ± 0.350	
			2.0	**41.10 ± 5.82**	**2.15E-06 ± 7.23E-07**	**4.481 ± 0.634**	
VHF TV	174 - 230	28	1.0	2.26 ± 0.33	6.40E-09 ± 9.06E-10	0.012 ± 0.002	**3.51 ± 0.50**
			1.5	4.75 ± 0.68	2.91E-08 ± 6.03E-09	0.061 ± 0.009	
			1.7	3.56 ± 0.51	1.62E-08 ± 1.19E-09	0.032 ± 0.005	
			2.0	**2.98 ± 0.42**	**1.12E-08 ± 1.58E-09**	**0.021 ± 0.003**	
UHF TV	470 - 862	30	1.0	16.59 ± 2.35	3.06E-07 ± 1.12E-07	0.731 ± 0.103	**18.12 ± 2.56**
			1.5	12.57 ± 1.78	1.75E-07 ± 7.20E-08	0.421 ± 0.059	
			1.7	16.23 ± 2.30	2.93E-07 ± 9.25E-08	0.701 ± 0.099	
			2.0	**24.83 ± 3.51**	**6.85E-07 ± 1.32E-07**	**1.642 ± 0.231**	
GSM 900	925 - 960	42	1.0	110.36 ± 15.62	6.90E-06 ± 3.23E-06	32.311 ± 4.571	**132.05 ± 18.69**
			1.5	124.08 ± 17.56	8.73E-06 ± 4.54E-06	40.842 ± 5.779	
			1.7	148.32 ± 20.99	1.25E-05 ± 6.08E-06	58.351 ± 8.257	
			2.0	**142.04 ± 20.10**	**1.14E-05 ± 1.27E-05**	**53.521 ± 7.572**	
GSM 1800	1805-1910	58	1.0	119.64 ± 16.93	4.26E-06 ± 2.55E-06	37.971 ± 5.372	**91.01 ± 12.88**
			1.5	86.57 ± 12.25	2.23E-06 ± 2.25E-06	19.882 ± 2.813	
			1.7	73.98 ± 10.47	1.63E-06 ± 2.24E-06	14.521 ± 2.054	
			2.0	**76.51 ± 10.83**	**1.74E-06 ± 3.00E-06**	**15.531 ± 2.197**	
UMTS (WCDMA/3G)	2110-2170	61	1.0	331.85 ± 46.96	2.96E-05 ± 3.96E-06	292.110 ± 41.333	**192.61 ± 27.25**
			1.5	126.75 ± 17.94	4.32E-06 ± 2.77E-07	42.612 ± 6.030	
			1.7	105.57 ± 14.94	2.99E-06 ± 1.09E-06	29.561 ± 4.183	
			2.0	105.19 ± 14.88	2.97E-06 ± 5.66E-07	29.351 ± 4.153	

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Table A32- Summary of Numerical Results for Fort Orange

Band	Frequency (MHz)	Reference level (V/m)	Height (m)	Measured value (mV/m)	Exposure quotient	Power density (μW/m²)	Spatial average (mV/m)
FM broadcast	87.5 - 108	28	1.0	32.21 ± 4.57	1.32E-06 ± 8.43E-07	2.751 ± 0.391	31.35 ± 4.45
			1.5	32.27 ± 4.58	1.33E-06 ± 6.56E-07	2.762 ± 0.392	
			1.7	32.85 ± 4.66	1.38E-06 ± 4.57E-07	2.862 ± 0.406	
			2.0	**27.83 ± 3.95**	**9.88E-07 ± 7.26E-07**	**2.051 ± 0.292**	
VHF TV	174 - 230	28	1.0	1.23 ± 0.17	1.95E-09 ± 9.09E-10	0.011 ± 0.001	2.79 ± 0.40
			1.5	3.72 ± 0.52	1.80E-08 ± 6.05E-09	0.042 ± 0.005	
			1.7	2.51 ± 0.34	8.37E-09 ± 1.19E-09	0.021 ± 0.002	
			2.0	**2.89 ± 0.40**	**1.10E-08 ± 1.59E-09**	**0.023 ± 0.003**	
UHF TV	470 - 862	30	1.0	112.85 ± 16.02	1.42E-05 ± 1.13E-07	33.782 ± 4.797	144.04 ± 20.45
			1.5	12.59 ± 1.79	1.76E-05 ± 7.23E-08	0.421 ± 0.060	
			1.7	179.19 ± 25.44	3.57E-05 ± 9.29E-08	85.171 ± 12.094	
			2.0	**149.32 ± 21.20**	**2.48E-05 ± 1.32E-07**	**59.142 ± 8.398**	
GSM 900	925 - 960	42	1.0	109.10 ± 15.53	6.87E-06 ± 3.24E-06	31.181 ± 4.545	141.86 ± 20.14
			1.5	124.06 ± 17.62	8.72E-06 ± 4.56E-06	40.822 ± 5.797	
			1.7	177.54 ± 25.21	1.79E-05 ± 6.11E-06	83.612 ± 11.872	
			2.0	**146.49 ± 20.80**	**1.22E-05 ± 1.27E-05**	**56.921 ± 8.083**	
GSM 1800	1805-1910	58	1.0	216.78 ± 30.78	1.40E-05 ± 2.56E-06	124.651 ± 17.700	218.19 ± 30.98
			1.5	216.59 ± 30.76	1.39E-05 ± 2.26E-06	124.432 ± 17.669	
			1.7	310.68 ± 44.12	2.87E-05 ± 2.24E-06	256.032 ± 36.356	
			2.0	**212.69 ± 30.20**	**1.34E-05 ± 3.01E-06**	**119.991 ± 17.039**	
UMTS (WCDMA/3G)	2110-2170	61	1.0	321.33 ± 45.63	2.96E-05 ± 3.98E-06	273.881 ± 38.89	168.48 ± 23.92
			1.5	37.55 ± 5.33	3.79E-07 ± 2.78E-07	3.742 ± 0.531	
			1.7	34.28 ± 4.87	3.16E-07 ± 1.09E-06	3.122 ± 0.443	
			2.0	**29.01 ± 4.12**	**2.26E-07 ± 5.68E-07**	**2.233 ± 0.317**	

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Table A33- Summary of Numerical Results for Essipong

Band	Frequency (MHz)	Reference level (V/m)	Height (m)	Measured value (mV/m)	Exposure quotient	Power density (μW/m²)	Spatial Average (mV/m)
FM broadcast	87.5 - 108	28	1.0	3.89 ± 0.55	1.94E-08 ± 2.75E-09	0.041 ± 0.006	**3.66 ± 0.52**
			1.5	4.34 ± 0.61	2.40E-08 ± 3.40E-09	0.051 ± 0.007	
			1.7	3.49 ± 0.49	1.56E-08 ± 2.21E-09	0.033 ± 0.005	
			2.0	**2.73 ± 0.39**	**9.49E-09 ± 1.34E-09**	**0.022 ± 0.003**	
VHF TV	174 - 230	28	1.0	3.24 ± 0.46	1.34E-08 ± 1.90E-09	0.033 ± 0.004	**3.85 ± 0.54**
			1.5	5.78 ± 0.82	4.26E-08 ± 6.03E-09	0.099 ± 0.013	
			1.7	2.57 ± 0.36	8.39E-09 ± 1.19E-09	0.032 ± 0.002	
			2.0	**2.97 ± 0.42**	**1.12E-08 ± 1.58E-09**	**0.032 ± 0.003**	
UHF TV	470 - 862	30	1.0	6.59 ± 0.93	4.83E-08 ± 6.83E-09	0.132 ± 0.016	**15.44 ± 2.18**
			1.5	12.57 ± 1.78	1.75E-07 ± 2.48E-08	0.412 ± 0.059	
			1.7	12.91 ± 1.83	1.85E-07 ± 2.62E-08	0.424 ± 0.063	
			2.0	**24.19 ± 3.42**	**6.50E-07 ± 9.20E-08**	**1.556 ± 0.220**	
GSM 900	925 - 960	42	1.0	124.29 ± 17.59	8.76E-06 ± 1.24E-06	40.981 ± 5.798	**143.60 ± 20.32**
			1.5	146.51 ± 20.73	1.22E-05 ± 1.73E-06	56.954 ± 8.057	
			1.7	178.32 ± 25.23	1.80E-05 ± 2.55E-06	84.334 ± 11.935	
			2.0	**117.37 ± 16.61**	**7.81E-06 ± 1.11E-06**	**36.544 ± 5.170**	
GSM 1800	1805-1910	58	1.0	20.27 ± 2.87	1.22E-07 ± 1.73E-08	1.092 ± 0.154	**11.34 ± 1.60**
			1.5	5.98 ± 0.85	1.06E-08 ± 1.50E-09	0.098 ± 0.013	
			1.7	5.91 ± 0.84	1.04E-08 ± 1.47E-09	0.099 ± 0.013	
			2.0	**5.71 ± 0.81**	**9.68E-09 ± 1.37E-09**	**0.089 ± 0.012**	
UMTS (WCDMA/3G)	2110-2170	61	1.0	71.81 ± 10.16	2.61E-05 ± 3.69E-06	13.678 ± 1.935	**71.90 ± 10.17**
			1.5	67.84 ± 9.60	1.24E-06 ± 1.75E-07	12.231 ± 1.727	
			1.7	50.05 ± 7.08	6.73E-07 ± 9.52E-08	6.644 ± 0.940	
			2.0	**91.74 ± 12.98**	**2.26E-06 ± 3.20E-07**	**22.332 ± 3.159**	

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Table A34- Summary of Numerical Results for Takoradi Harbour

Band	Frequency (MHz)	Reference level (V/m)	Height (m)	Measured value (mV/m)	Exposure quotient	Power density (μW/m²)	Spatial Average (mV/m)
			1.0	39.25 ± 5.66	1.97E-06 ± 2.84E-07	4.093 ± 0.589	
			1.5	34.12 ± 4.92	1.49E-06 ± 2.15E-07	3.092 ± 0.445	
FM broadcast	87.5 - 108	28	1.7	30.53 ± 4.40	1.19E-06 ± 1.72E-07	2.473 ± 0.357	**36.49 ± 5.26**
			2.0	**41.10 ± 5.93**	**2.15E-06 ± 3.10E-07**	**4.481 ± 0.646**	
			1.0	4.13 ± 0.60	2.18E-08 ± 3.14E-09	0.053 ± 0.007	
			1.5	3.31 ± 0.48	1.40E-08 ± 2.02E-09	0.034 ± 0.004	
VHF TV	174 - 230	28	1.7	10.50 ± 1.51	1.41E-07 ± 2.03E-08	0.292 ± 0.042	**6.06 ± 0.87**
			2.0	**2.99 ± 0.43**	**1.12E-08 ± 1.62E-09**	**0.023 ± 0.003**	
			1.0	6.59 ± 0.95	4.83E-08 ± 6.96E-09	0.121 ± 0.017	
			1.5	12.57 ± 1.81	1.75E-07 ± 2.52E-08	0.423 ± 0.060	
UHF TV	470 - 862	30	1.7	16.23 ± 2.34	2.93E-07 ± 4.23E-08	0.702 ± 0.101	**16.44 ± 2.37**
			2.0	**24.83 ± 3.58**	**6.85E-07 ± 9.38E-08**	**1.642 ± 0.236**	
			1.0	134.29 ± 19.36	1.02E-05 ± 1.47E-06	47.842 ± 6.898	
			1.5	146.51 ± 21.13	1.22E-05 ± 1.76E-06	56.942 ± 8.210	**147.92 ± 21.33**
GSM 900	925 - 960	42	1.7	178.32 ± 25.71	1.80E-05 ± 2.60E-06	84.342 ± 12.16	
			2.0	**127.37 ± 18.37**	**9.20E-06 ± 1.33E-06**	**43.033 ± 6.205**	
			1.0	43.12 ± 6.22	5.53E-07 ± 7.97E-08	4.934 ± 0.711	
			1.5	31.64 ± 4.56	2.97E-07 ± 4.28E-08	2.662 ± 0.383	
GSM 1800	1805-1910	58	1.7	50.36 ± 7.26	7.54E-07 ± 1.09E-07	6.733 ± 0.970	**40.23 ± 5.80**
			2.0	**32.85 ± 4.74**	**3.21E-07 ± 4.63E-08**	**2.861 ± 0.413**	
			1.0	111.85 ± 16.13	2.96E-05 ± 4.27E-06	33.185 ± 4.785	
			1.5	109.79 ± 15.83	3.24E-06 ± 4.67E-07	31.972 ± 4.611	
UMTS (WCDMA/3G)	2110-2170	61	1.7	106.69 ± 15.38	3.06E-06 ± 4.41E-07	30.192 ± 4.354	**108.97 ± 15.71**
			2.0	**107.48 ± 15.21**	**3.10E-06 ± 4.47E-07**	**30.641 ± 4.419**	

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Table A35- Summary of Numerical Results for Market Circle

Band	Frequency (MHz)	Reference (V/m) level	Height (m)	Measured value (mV/m)	Exposure quotient	Power density (μW/m²)	Spatial Average (mV/m)
			1.0	150.87 ± 21.57	2.90E-05 ± 4.15E-06	60.38 ± 8.63	
			1.5	262.14 ± 37.49	8.76E-05 ± 1.25E-05	182.27 ± 26.07	
FM broadcast	87.5 - 108	28	1.7	253.19 ± 36.21	8.18E-05 ± 1.17E-05	170.04 ± 24.32	**208.00 ± 29.74**
			2.0	**132.28 ± 18.92**	**2.23E-05 ± 3.19E-06**	**46.41 ± 6.64**	
			1.0	11.14 ± 1.59	1.58E-07 ± 2.26E-08	0.33 ± 0.05	
			1.5	11.47 ± 1.64	1.68E-07 ± 2.40E-08	0.35 ± 0.05	
VHF TV	174 - 230	28	1.7	10.50 ± 1.50	1.41E-07 ± 2.02E-08	0.29 ± 0.04	**11.31 ± 1.62**
			2.0	**12.08 ± 1.73**	**1.86E-07 ± 2.66E-08**	**0.39 ± 0.06**	
			1.0	16.59 ± 2.37	3.06E-07 ± 4.38E-08	0.73 ± 0.10	
			1.5	12.57 ± 1.80	1.75E-07 ± 2.50E-08	0.42 ± 0.06	
UHF TV	470 - 862	30	1.7	16.23 ± 2.32	2.93E-07 ± 4.19E-08	0.70 ± 0.10	**15.14 ± 2.17**
			2.0	**14.83 ± 2.12**	**2.44E-07 ± 3.49E-08**	**0.58 ± 0.08**	
			1.0	130.36 ± 18.64	9.63E-06 ± 1.38E-06	45.08 ± 6.45	
			1.5	124.08 ± 17.74	8.73E-06 ± 1.25E-06	40.84 ± 5.84	
GSM 900	925 - 960	42	1.7	158.32 ± 22.64	1.42E-05 ± 2.03E-06	66.49 ± 9.51	**139.31 ± 19.92**
			2.0	**142.04 ± 20.31**	**1.14E-05 ± 1.63E-06**	**53.52 ± 7.65**	
			1.0	50.86 ± 7.27	7.69E-07 ± 1.10E-07	6.86 ± 0.98	
			1.5	33.44 ± 4.78	3.32E-07 ± 4.75E-08	2.97 ± 0.42	
GSM 1800	1805-1910	58	1.7	48.45 ± 6.93	6.98E-07 ± 9.98E-08	6.23 ± 0.89	**40.64 ± 5.81**
			2.0	**23.55 ± 3.37**	**1.65E-07 ± 2.36E-08**	**1.47 ± 0.21**	
			1.0	112.35 ± 16.07	2.96E-05 ± 4.23E-06	33.48 ± 4.79	
			1.5	121.24 ± 17.34	2.47E-06 ± 3.53E-07	38.99 ± 5.58	
UMTS	2110-2170	61	1.7	113.10 ± 16.17	2.86E-06 ± 4.09E-07	33.93 ± 4.85	**110.56 ± 15.81**
(WCDMA/3G)			**2.0**	**104.60 ± 14.96**	**2.94E-06 ± 4.20E-07**	**29.02 ± 4.15**	

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Table A36- Summary of Numerical Results for DuPaul

Band	Frequency (MHz)	Reference level (V/m)	Height (m)	Measured value (mV/m)	Exposure quotient	Power density (μW/m²)	Spatial Average (mV/m)
			1.0	47.44 ± 6.69	2.87E-06 ± 4.05E-07	5.971 ± 0.842	
			1.5	46.18 ± 6.50	2.71E-06 ± 3.82E-07	5.642 ± 0.795	
FM broadcast	87.5 - 108	28	1.7	34.99 ± 4.93	1.56E-06 ± 2.20E-07	3.252 ± 0.458	**46.16 ± 6.51**
			2.0	**54.05 ± 7.62**	**3.73E-06 ± 5.26E-07**	**7.753 ± 1.093**	
			1.0	2.27 ± 0.32	6.40E-09 ± 9.02E-10	0.012 ± 0.002	
			1.5	5.76 ± 0.81	4.26E-08 ± 6.01E-09	0.092 ± 0.012	
VHF TV	174 - 230	28	1.7	2.66 ± 0.36	8.39E-09 ± 1.18E-09	0.023 ± 0.002	**3.66 ± 0.52**
			2.0	**2.89 ± 0.42**	**1.12E-08 ± 1.58E-09**	**0.023 ± 0.003**	
			1.0	12.56 ± 1.77	1.75E-07 ± 2.47E-08	0.424 ± 0.059	
			1.5	12.56 ± 1.77	1.75E-07 ± 2.47E-08	0.424 ± 0.059	
UHF TV	470 - 862	30	1.7	16.23 ± 2.29	2.93E-07 ± 4.13E-08	0.702 ± 0.098	**17.29 ± 2.44**
			2.0	**24.83 ± 3.50**	**6.85E-07 ± 9.66E-08**	**1.643 ± 0.231**	
			1.0	124.28 ± 17.52	8.76E-06 ± 1.24E-06	40.971 ± 5.777	
			1.5	146.51 ± 20.66	1.22E-05 ± 1.72E-06	56.942 ± 8.029	
GSM 900	925 - 960	42	1.7	178.32 ± 25.14	1.80E-05 ± 2.54E-06	84.343 ± 11.892	**143.61 ± 20.25**
			2.0	**117.37 ± 16.55**	**7.81E-06 ± 1.10E-06**	**36.542 ± 5.153**	
			1.0	26.89 ± 3.79	2.15E-07 ± 3.03E-08	1.922 ± 0.271	
			1.5	15.13 ± 2.13	6.81E-08 ± 9.60E-09	0.611 ± 0.086	
GSM 1800	1805-1910	58	1.7	16.26 ± 2.29	7.86E-08 ± 1.11E-08	0.702 ± 0.099	**18.46 ± 2.60**
			2.0	**12.07 ± 1.70**	**4.34E-08 ± 6.12E-09**	**0.392 ± 0.055**	
			1.0	113.85 ± 16.05	4.60E-05 ± 6.49E-06	34.383 ± 4.848	
			1.5	91.33 ± 12.88	2.24E-06 ± 3.16E-07	22.133 ± 3.120	
UMTS	2110-2170	61	1.7	103.17 ± 14.54	2.86E-06 ± 4.03E-07	28.201 ± 3.976	**115.49 ± 16.28**
(WCDMA/3G)			**2.0**	**146.34 ± 20.63**	**5.76E-06 ± 8.12E-07**	**56.801 ± 8.009**	

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Table A37- Spatial Average Plane-wave Electric Field Strengths at all Locations in mVm^{-1}

Measurement Locations	FM broadcast	VHF TV	UHF TV	GSM 900	GSM 1800	UMTS (WCDMA/3G)
Abeka Junction	72.3 ± 10.4	5.9 ± 0.9	86.3 ± 12.4	313.1 ± 45.1	262.1 ± 37.8	242.1 ± 34.9
Airport Aviance	50.5 ± 7.2	5.5 ± 0.8	84.7 ± 12.0	504.4 ± 71.3	281.4 ± 39.8	339.1 ± 47.9
Comet Hills	3.4 ± 0.5	4.1 ± 0.6	1.7 ± 0.3	5.9 ± 0.8	5.08 ± 0.71	5.24 ± 0.73
Korle-Bu Teaching Hospital	24.4 ± 3.4	5.9 ± 0.8	71.7 ± 10.0	230.9 ± 32.3	246.3 ± 34.4	55.4 ± 7.7
McCarthy Hill	138.9 ± 19.6	5.8 ± 0.8	31.9 ± 4.5	545.7 ± 76.4	306.8 ± 43.3	271.4 ± 38.3
Rawlings Park	3.1 ± 0.4	0.9 ± 0.1	16.9 ± 2.4	293.5 ± 41.8	196.9 ± 28.0	221.5 ± 31.5
Sakumono Total Filling Station	139.1 ± 19.8	5.9 ± 0.3	65.4 ± 9.3	318.5 ± 45.2	266.5 ± 37.8	211.5 ± 30.0
Tema Community One	139.3 ± 19.9	6.1 ± 0.9	87.1± 12.5	651.4 ± 93.2	290.3 ± 41.2	790.6 ± 113.1
Tema Roundabout	18.5 ± 2.6	5.8 ± 0.8	93.3 ± 13.2	363.8 ± 51.4	320.9 ± 51.4	197.5 ± 27.9
University Of Ghana	476.8 ± 68.4	5.9 ±0.8	86.3 ± 12.4	638.1 ± 91.5	299.3 ± 42.9	892.4 ± 127.9
Adum	627.6 ± 88.8	101.1 ± 14.3	103.1 ± 14.6	173.4 ± 24.5	191.9 ± 27.2	230.1 ± 32.6
Airport Roundabout	120.1 ± 17.2	14.6 ± 2.1	43.1 ± 6.2	173.4 ± 24.8	76.7 ± 10.9	216.5 ± 30.7
Amakom Baba Yara Stadium	304.1 ± 43.8	458.3 ± 65.9	158.8 ± 22.9	93.4 ± 13.4	51.4 ± 8.8	39.1 ± 5.6
Bremang	14.6 ± 2.1	12.6 ± 1.8	50.9 ± 7.2	180.9 ± 25.7	85.9 ± 12.2	122.9 ± 17.5
Manhyia	1181.8 ± 166.6	9.9 ± 1.4	194.7 ± 27.4	284.4 ± 40.1	55.4 ± 7.8	185.6 ± 26.2
Melcom	102.3 ± 14.6	103.4 ± 14.7	125.5 ± 17.9	93.4 ± 13.3	61.4 ± 8.7	139.7 ± 19.9
Prempeh College	151.9 ± 21.7	10.4 ± 1.5	54.5 ± 7.8	222.2 ± 31.8	160.9 ± 23.0	189.9 ± 27.2
Santasi Roundabout	284.5 ± 40.5	103.3 ± 14.7	158.8 ± 22.6	248.3 ± 35.4	162.1 ± 23.1	121.7 ± 17.3
UEW College of Technology	45.6 ± 6.5	10.1 ± 1.5	43.9 ± 6.3	116.3 ± 16.7	63.6 ± 9.1	148.9 ± 21.4
Wesley Girls SHS	31.1 ± 4.5	9.8 ± 1.4	101.3 ± 14.6	143.3 ± 20.6	55.8 ± 8.0	196.8 ± 28.3
Anaji Westline	60.8 ± 8.6	3.7 ± 05	25.5 ± 3.6	287.4 ± 40.7	244.4 ± 34.6	187.1 ± 26.5
DuPaul	46.1 ± 6.5	3.7 ± 0.5	17.3 ± 2.4	143.6 ± 20.2	18.5 ± 2.6	230.0 ± 32.4
Essipon Sekondi	3.7 ± 0.5	3.8 ± 0.5	15.4 ± 2.2	143.6 ± 20.3	11.3 ± 1.6	167.9 ± 23.7
Fort-Orange Sekondi	31.4 ± 4.5	2.8 ± 0.4	144.0 ± 20.4	141.8 ± 20.1	218.1 ± 30.9	168.4 ± 23.9
Galaxy	35.1 ± 4.9	2.7 ± 0.4	25.4 ± 3.6	135.8 ± 19.2	97.5 ± 13.8	183.6 ± 25.9
Habour	36.5 ± 5.2	6.1 ± 0.9	16.4 ± 2.4	147.9 ± 21.3	40.2 ± 5.8	190.5 ± 27.5
Lagos Town	36.4 ± 5.2	3.5 ± 0.5	18.1 ± 2.6	132.0 ± 18.7	91.1 ± 13.9	192.6 ± 27.3
Market Circle	208.0 ± 29.7	11.3 ± 1.6	15.1 ± 2.2	139.3 ± 19.9	40.6 ± 5.8	187.7 ± 26.8
T-Technical University	41.1 ± 5.8	3.0 ± 0.4	25.5 ± 3.6	120.9 ± 17.1	95.0 ± 13.4	140.1 ± 19.8
Vienna City Round About	56.9 ± 8.0	1.7 ± 0.23	16.6 ± 2.3	133.7 ± 2.3	83.8 ± 11.8	120.1 ± 19.7

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Table A38- Calculated Impedance Values for Tissues of Concern

RF Sources	Frequency Band /MHz	Impedance values/Ω			
		Skin (Dry)	Skin (Wet)	Eye (Sclera)	Eye (Cornea)
FM Broadcast	87.5 - 108	39.14	40.14	35.79	33.67
VHF TV	175 - 230	46.65	46.63	42.12	40.17
UHF TV	470 - 862	55.16	53.1 1	48.37	47.52
GSM 900	925 - 960	57.58	54.77	49.75	49.43
GSM180	1805-1910	59.81	56.39	50.96	51.16
UMTS/WCDMA/3G	2110-2170	60.36	56.88	51.32	51.63

Table A39- Calculated Transmission coefficients of Selected Tissues

RF Sources	Frequency Band /MHz	Transmission coefficients			
		Skin (Dry)	Skin (Wet)	Eye (Sclera)	Eye (Cornea)
FM Broadcast	87.5 - 108	0.1882	0.1926	0.1735	0.1641
VHF TV	175 - 230	0.2204	0.2203	0.2011	0.1927
UHF TV	470 - 862	0.2554	0.2471	0.2276	0.2240
GSM 900	925 - 960	0.2652	0.2539	0.2333	0.2320
GSM180	1805-1910	0.2740	0.2604	0.2383	0.2391
UMTS/WCDMA/3G	2110-2170	0.2762	0.2623	0.2398	0.2411

Table A40- Calculated Electrical Conductivity of Selected Tissues

RF Sources	Frequency Band /MHz	Electrical conductivity/Sm^{-1}			
		Skin (Dry)	Skin (Wet)	Eye (Sclera)	Eye (Cornea)
FM Broadcast	87.5 - 108	0.4882	0.5212	0.9032	1.0347
VHF TV	175 - 230	0.5755	0.5813	0.9415	1.0977
UHF TV	470 - 862	0.7614	0.7358	1.0614	1.2680
GSM 900	925 - 960	0.8808	0.8603	1.1829	1.4125
GSM180	1805-1910	1.1990	1.2503	1.6232	1.8801
UMTS/WCDMA/3G	2110-2170	1.3239	1.4109	1.8145	2.0749

Table A41- Calculated Permittivity of Selected Tissues

RF Sources	Frequency Band /MHz	Permittivity/Fm^{-1}			
		Skin (Dry)	Skin (Wet)	Eye (Sclera)	Eye (Cornea)
FM Broadcast	87.5 - 108	73.8422	66.4889	68.2336	76.5776
VHF TV	175 - 230	55.7330	55.6699	61.2305	65.2933
UHF TV	470 - 862	43.8236	47.8532	56.4119	57.1253
GSM 900	925 - 960	41.1957	45.9167	55.1587	55.0575
GSM180	1805-1910	38.8138	43.7890	53.5133	52.6971
UMTS/WCDMA/3G	2110-2170	38.3807	43.3064	53.0701	52.1425

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Table A42- Estimated Plane-wave Electric Field Transmitted into Dry Skin in V/m.

Measurement Locations	FM broadcast	VHF TV	UHF TV	GSM 900	GSM 1800	UMTS (WCDMA/3G)
Abeka Junction	0.0136 ± 0.0020	0.0013 ± 0.0002	0.0220 ± 0.0032	0.0830 ± 0.0119	0.0718 ± 0.0104	0.0669 ± 0.0096
Airport Aviance	0.0095 ± 0.0013	0.0012 ± 0.0002	0.0216 ± 0.0031	0.1338 ± 0.0189	0.0771 ± 0.0109	0.0937 ± 0.0132
Comet Hills	0.0028 ± 0.0004	0.0007 ± 0.0001	0.0019 ± 0.0003	0.0002 ± 0.0000	0.0004 ± 0.0001	0.0000 ± 0.0001
Korle-Bu Teaching Hospital	0.0046 ± 0.0006	0.0013 ± 0.0002	0.0183 ± 0.0026	0.0612 ± 0.0085	0.0675 ± 0.0095	0.0153 ± 0.0021
McCarthy Hill	0.0261 ± 0.0037	0.0013 ± 0.0002	0.0081 ± 0.0011	0.1447 ± 0.0204	0.0841 ± 0.0119	0.0750 ± 0.0106
Rawlings Park	0.0006 ± 0.0001	0.0002 ± 0.0000	0.0043 ± 0.0006	0.0778 ± 0.0110	0.0540 ± 0.0077	0.0612 ± 0.0087
Sakumono Total Filling Station	0.0262 ± 0.0037	0.0013 ± 0.0002	0.0167 ± 0.0024	0.0845 ± 0.0120	0.0730 ± 0.0104	0.0584 ± 0.0084
Tema Community One	0.0262 ± 0.0037	0.0013 ± 0.0002	0.0222 ± 0.0032	0.1728 ± 0.0245	0.0820 ± 0.0116	0.2184 ± 0.0310
Tema Roundabout	0.0035 ± 0.0005	0.0013 ± 0.0002	0.0238 ± 0.0034	0.0965 ± 0.0136	0.0879 ± 0.0124	0.0545 ± 0.0077
University Of Ghana	0.0897 ± 0.0129	0.0013 ± 0.0002	0.0220 ± 0.0032	0.1692 ± 0.0242	0.0820 ± 0.0118	0.2465 ± 0.0353
Adum	0.1181 ± 0.0167	0.0223 ± 0.0032	0.0263 ± 0.0037	0.0460 ± 0.0065	0.0526 ± 0.0074	0.0636 ± 0.0090
Airport Roundabout	0.0226 ± 0.0032	0.0032 ± 0.0005	0.0110 ± 0.0016	0.0460 ± 0.0065	0.0210 ± 0.0030	0.0598 ± 0.0086
Amakom Baba Yara Stadium	0.0572 ± 0.0082	0.1010 ± 0.0145	0.0406 ± 0.0058	0.0248 ± 0.0035	0.0168 ± 0.0024	0.0108 ± 0.0016
Bremang	0.0027 ± 0.0004	0.0028 ± 0.0004	0.0130 ± 0.0018	0.0480 ± 0.0068	0.0235 ± 0.0033	0.0339 ± 0.0048
Manhyia	0.2224 ± 0.0314	0.0022 ± 0.0003	0.0497 ± 0.0070	0.0754 ± 0.0106	0.0152 ± 0.0021	0.0513 ± 0.0072
Melcom	0.0193 ± 0.0028	0.0228 ± 0.0032	0.0321 ± 0.0046	0.0248 ± 0.0035	0.0168 ± 0.0024	0.0386 ± 0.0055
Prempeh College	0.0286 ± 0.0041	0.0023 ± 0.0003	0.0139 ± 0.0020	0.0589 ± 0.0084	0.0441 ± 0.0063	0.0525 ± 0.0075
Santasi Roundabout	0.0535 ± 0.0076	0.0228 ± 0.0032	0.0406 ± 0.0058	0.0658 ± 0.0093	0.0444 ± 0.0063	0.0336 ± 0.0048
UEW College of Technology	0.0086 ± 0.0012	0.0022 ± 0.0003	0.0112 ± 0.0016	0.0308 ± 0.0044	0.0174 ± 0.0025	0.0411 ± 0.0059
Wesley Girls SHS	0.0059 ± 0.0008	0.0022 ± 0.0003	0.0259 ± 0.0037	0.0380 ± 0.0054	0.0153 ± 0.0022	0.0544 ± 0.0078
Anaji Westline	0.0114 ± 0.0016	0.0008 ± 0.0001	0.0065 ± 0.0009	0.0762 ± 0.0107	0.0670 ± 0.0095	0.0517 ± 0.0073
DuPaul	0.0087 ± 0.0012	0.0008 ± 0.0001	0.0044 ± 0.0006	0.0381 ± 0.0053	0.0051 ± 0.0007	0.0635 ± 0.0090
Essipon Sekondi	0.0007 ± 0.0001	0.0008 ± 0.0001	0.0039 ± 0.0006	0.0381 ± 0.0053	0.0031 ± 0.0004	0.0464 ± 0.0066
Fort-Orange Sekondi	0.0059 ± 0.0008	0.0006 ± 0.0001	0.0368 ± 0.0052	0.0376 ± 0.0053	0.0598 ± 0.0085	0.0465 ± 0.0066
Galaxy	0.0066 ± 0.0009	0.0006 ± 0.0001	0.0065 ± 0.0009	0.0360 ± 0.0050	0.0267 ± 0.0038	0.0507 ± 0.0072
Habour	0.0069 ± 0.0010	0.0013 ± 0.0002	0.0042 ± 0.0006	0.0392 ± 0.0056	0.0110 ± 0.0016	0.0526 ± 0.0076
Lagos Town	0.0069 ± 0.0010	0.0008 ± 0.0001	0.0046 ± 0.0007	0.0350 ± 0.0049	0.0250 ± 0.0035	0.0532 ± 0.0075
Market Circle	0.0391 ± 0.0056	0.0025 ± 0.0004	0.0039 ± 0.0006	0.0369 ± 0.0052	0.0111 ± 0.0016	0.0518 ± 0.0074
T-Technical University	0.0077 ± 0.0011	0.0007 ± 0.0001	0.0065 ± 0.0009	0.0321 ± 0.0045	0.0260 ± 0.0037	0.0387 ± 0.0055
Vienna City Round about	0.0107 ± 0.0015	0.0004 ± 0.0001	0.0042 ± 0.0006	0.0355 ± 0.0050	0.0230 ± 0.0032	0.0332 ± 0.0047

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Table A43- Estimated Plane-wave Electric Field Transmitted into Wet Skin in V/m

Measurement Locations	FM broadcast	VHF TV	UHF TV	GSM 900	GSM 1800	UMTS (WCDMA/3G)
Abeka Junction	0.0139 ± 0.0020	0.0013 ± 0.0002	0.0213 ± 0.0031	0.0795 ± 0.0115	0.0683 ± 0.0098	0.0635 ± 0.00916
Airport Aviance	0.0097 ± 0.0014	0.0012 ± 0.0002	0.0209 ± 0.0030	0.1281 ± 0.0181	0.0733 ± 0.0104	0.0889 ± 0.01257
Comet Hills	0.0029 ± 0.0004	0.0007 ± 0.0001	0.0019 ± 0.0003	0.0002 ± 0.0000	0.0004 ± 0.0001	0.0001 ± 0.00001
Korle-Bu Teaching Hospital	0.0047 ± 0.0007	0.0013 ± 0.0002	0.0177 ± 0.0025	0.0586 ± 0.0082	0.0641 ± 0.0090	0.0145 ± 0.00203
McCarthy Hill	0.0268 ± 0.0038	0.0013 ± 0.0002	0.0079 ± 0.0011	0.1386 ± 0.0195	0.0799 ± 0.0113	0.0712 ± 0.01004
Rawlings Park	0.0006 ± 0.0001	0.0002 ± 0.0000	0.0042 ± 0.0006	0.0745 ± 0.0106	0.0513 ± 0.0073	0.0581 ± 0.00827
Sakumono Total Filling Station	0.0268 ± 0.0038	0.0013 ± 0.0002	0.0162 ± 0.0023	0.0809 ± 0.0116	0.0694 ± 0.0099	0.0555 ± 0.00794
Tema Community One	0.0268 ± 0.0038	0.0013 ± 0.0002	0.0215 ± 0.0031	0.1654 ± 0.0235	0.0779 ± 0.0111	0.2074 ± 0.02945
Tema Roundabout	0.0036 ± 0.0005	0.0013 ± 0.0002	0.0231 ± 0.0033	0.0924 ± 0.0130	0.0836 ± 0.0118	0.0518 ± 0.00731
University Of Ghana	0.0918 ± 0.0132	0.0013 ± 0.0002	0.0213 ± 0.0031	0.1620 ± 0.0232	0.0779 ± 0.0112	0.2341 ± 0.03357
Adum	0.1209 ± 0.0171	0.0223 ± 0.0032	0.0255 ± 0.0036	0.0440 ± 0.0062	0.0500 ± 0.0071	0.0604 ± 0.00855
Airport Roundabout	0.0231 ± 0.0033	0.0032 ± 0.0005	0.0107 ± 0.0015	0.0440 ± 0.0063	0.0200 ± 0.0029	0.0568 ± 0.00812
Amakom Baba Yara Stadium	0.0586 ± 0.0084	0.1009 ± 0.0145	0.0392 ± 0.0056	0.0237 ± 0.0034	0.0160 ± 0.0023	0.0103 ± 0.00148
Bremang	0.0028 ± 0.0004	0.0028 ± 0.0004	0.0126 ± 0.0018	0.0459 ± 0.0065	0.0224 ± 0.0032	0.0322 ± 0.00457
Manhyia	0.2276 ± 0.0321	0.0022 ± 0.0003	0.0481 ± 0.0068	0.0722 ± 0.0102	0.0144 ± 0.0020	0.0487 ± 0.00687
Melcom	0.0197 ± 0.0028	0.0228 ± 0.0032	0.0310 ± 0.0044	0.0237 ± 0.0034	0.0160 ± 0.0023	0.0366 ± 0.00522
Prempeh College	0.0293 ± 0.0042	0.0023 ± 0.0003	0.0135 ± 0.0019	0.0564 ± 0.0081	0.0419 ± 0.0060	0.0498 ± 0.00712
Bantasi Roundabout	0.0548 ± 0.0078	0.0228 ± 0.0032	0.0392 ± 0.0056	0.0630 ± 0.0090	0.0422 ± 0.0060	0.0319 ± 0.00454
UEW College of Technology	0.0088 ± 0.0013	0.0022 ± 0.0003	0.0108 ± 0.0015	0.0295 ± 0.0042	0.0166 ± 0.0024	0.0391 ± 0.00561
Wesley Girls SHS	0.0060 ± 0.0009	0.0022 ± 0.0003	0.0250 ± 0.0036	0.0364 ± 0.0052	0.0145 ± 0.0021	0.0516 ± 0.00743
Anaji Westline	0.0117 ± 0.0017	0.0008 ± 0.0001	0.0063 ± 0.0009	0.0730 ± 0.0103	0.0636 ± 0.0090	0.0491 ± 0.00695
DuPaul	0.0089 ± 0.0013	0.0008 ± 0.0001	0.0043 ± 0.0006	0.0365 ± 0.0051	0.0048 ± 0.0007	0.0603 ± 0.00850
Essipon Sekondi	0.0007 ± 0.0001	0.0008 ± 0.0001	0.0038 ± 0.0005	0.0365 ± 0.0052	0.0029 ± 0.0004	0.0440 ± 0.00623
Fort-Orange Sekondi	0.0060 ± 0.0009	0.0006 ± 0.0001	0.0356 ± 0.0051	0.0360 ± 0.0051	0.0568 ± 0.0081	0.0442 ± 0.00628
Galaxy	0.0068 ± 0.0010	0.0006 ± 0.0001	0.0063 ± 0.0009	0.0345 ± 0.0049	0.0254 ± 0.0036	0.0482 ± 0.00682
Labour	0.0070 ± 0.0010	0.0013 ± 0.0002	0.0041 ± 0.0006	0.0376 ± 0.0054	0.0105 ± 0.0015	0.0500 ± 0.00721
Lagos Town	0.0070 ± 0.0010	0.0008 ± 0.0001	0.0045 ± 0.0006	0.0335 ± 0.0047	0.0237 ± 0.0034	0.0505 ± 0.00715
Market Circle	0.0401 ± 0.0057	0.0025 ± 0.0004	0.0037 ± 0.0005	0.0354 ± 0.0051	0.0106 ± 0.0015	0.0492 ± 0.00704
T-Technical University	0.0079 ± 0.0011	0.0007 ± 0.0001	0.0063 ± 0.0009	0.0307 ± 0.0043	0.0247 ± 0.0035	0.0367 ± 0.00519
Vienna City Round About	0.0110 ± 0.0016	0.0004 ± 0.0001	0.0041 ± 0.0006	0.0339 ± 0.0048	0.0218 ± 0.0031	0.0312 ± 0.00444

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Table A44- Estimated Plane-wave Electric Field Transmitted into the Sclera of the Eye in V/m

Measurement Locations	FM broadcast	VHF TV	UHF TV	GSM 900	GSM 1800	UMTS (WCDMA/3G)
Abeka Junction	0.0125 ± 0.0018	0.0012 ± 0.0002	0.0196 ± 0.0028	0.0730 ± 0.0105	0.0625 ± 0.0090	0.0581 ± 0.0084
Airport Aviance	0.0088 ± 0.0012	0.0011 ± 0.0002	0.0193 ± 0.0027	0.1177 ± 0.0166	0.0671 ± 0.0095	0.0813 ± 0.0115
Comet Hills	0.0026 ± 0.0004	0.0006 ± 0.0001	0.0017 ± 0.0002	0.0001 ± 0.0000	0.0004 ± 0.0001	0.0000 ± 0.0000
Korle-Bu Teaching Hospital	0.0042 ± 0.0006	0.0012 ± 0.0002	0.0163 ± 0.0023	0.0539 ± 0.0075	0.0587 ± 0.0082	0.0133 ± 0.0019
McCarthy Hill	0.0241 ± 0.0034	0.0012 ± 0.0002	0.0073 ± 0.0010	0.1273 ± 0.0179	0.0731 ± 0.0103	0.0651 ± 0.0092
Rawlings Park	0.0005 ± 0.0001	0.0002 ± 0.0000	0.0038 ± 0.0005	0.0685 ± 0.0098	0.0469 ± 0.0067	0.0531 ± 0.0076
Sakumono Total Filling Station	0.0241 ± 0.0034	0.0012 ± 0.0002	0.0149 ± 0.0021	0.0743 ± 0.0106	0.0635 ± 0.0091	0.0507 ± 0.0073
Tema Community One	0.0242 ± 0.0034	0.0012 ± 0.0002	0.0198 ± 0.0028	0.1520 ± 0.0216	0.0713 ± 0.0101	0.1896 ± 0.0269
Tema Roundabout	0.0032 ± 0.0005	0.0012 ± 0.0002	0.0212 ± 0.0030	0.0849 ± 0.0120	0.0765 ± 0.0108	0.0474 ± 0.0067
University Of Ghana	0.0827 ± 0.0119	0.0012 ± 0.0002	0.0196 ± 0.0028	0.1489 ± 0.0214	0.0713 ± 0.0102	0.2140 ± 0.0307
Adum	0.1089 ± 0.0154	0.0203 ± 0.0029	0.0235 ± 0.0033	0.0405 ± 0.0057	0.0457 ± 0.0065	0.0552 ± 0.0078
Airport Roundabout	0.0208 ± 0.0030	0.0029 ± 0.0004	0.0098 ± 0.0014	0.0405 ± 0.0058	0.0183 ± 0.0026	0.0519 ± 0.0074
Amakom Baba Yara Stadium	0.0528 ± 0.0076	0.0921 ± 0.0133	0.0361 ± 0.0052	0.0218 ± 0.0031	0.0146 ± 0.0021	0.0094 ± 0.0014
Bremang	0.0025 ± 0.0004	0.0025 ± 0.0004	0.0116 ± 0.0016	0.0422 ± 0.0060	0.0205 ± 0.0029	0.0295 ± 0.0042
Manhyia	0.2050 ± 0.0289	0.0020 ± 0.0003	0.0443 ± 0.0062	0.0664 ± 0.0094	0.0132 ± 0.0019	0.0445 ± 0.0063
Melcom	0.0177 ± 0.0025	0.0208 ± 0.0030	0.0286 ± 0.0041	0.0218 ± 0.0031	0.0146 ± 0.0021	0.0335 ± 0.0048
Prempeh College	0.0264 ± 0.0038	0.0021 ± 0.0003	0.0124 ± 0.0018	0.0518 ± 0.0074	0.0383 ± 0.0055	0.0455 ± 0.0065
Santasi Roundabout	0.0494 ± 0.0070	0.0208 ± 0.0030	0.0361 ± 0.0051	0.0579 ± 0.0082	0.0386 ± 0.0055	0.0292 ± 0.0042
UEW College of Technology	0.0079 ± 0.0011	0.0020 ± 0.0003	0.0100 ± 0.0014	0.0271 ± 0.0039	0.0152 ± 0.0022	0.0357 ± 0.0051
Wesley Girls SHS	0.0054 ± 0.0008	0.0020 ± 0.0003	0.0231 ± 0.0033	0.0334 ± 0.0048	0.0133 ± 0.0019	0.0472 ± 0.0068
Anaji Westline	0.0105 ± 0.0015	0.0007 ± 0.0001	0.0058 ± 0.0008	0.0671 ± 0.0095	0.0582 ± 0.0082	0.0449 ± 0.0064
DuPaul	0.0080 ± 0.0011	0.0007 ± 0.0001	0.0039 ± 0.0005	0.0335 ± 0.0047	0.0044 ± 0.0006	0.0552 ± 0.0078
Essipon Sekondi	0.0006 ± 0.0001	0.0008 ± 0.0001	0.0035 ± 0.0005	0.0335 ± 0.0047	0.0027 ± 0.0004	0.0403 ± 0.0057
Fort-Orange Sekondi	0.0054 ± 0.0008	0.0006 ± 0.0001	0.0328 ± 0.0047	0.0331 ± 0.0047	0.0520 ± 0.0074	0.0404 ± 0.0057
Galaxy	0.0061 ± 0.0009	0.0005 ± 0.0001	0.0058 ± 0.0008	0.0317 ± 0.0045	0.0232 ± 0.0033	0.0440 ± 0.0062
Habour	0.0063 ± 0.0009	0.0012 ± 0.0002	0.0037 ± 0.0005	0.0345 ± 0.0050	0.0096 ± 0.0014	0.0457 ± 0.0066
Lagos Town	0.0063 ± 0.0009	0.0007 ± 0.0001	0.0041 ± 0.0006	0.0308 ± 0.0044	0.0217 ± 0.0031	0.0462 ± 0.0065
Market Circle	0.0361 ± 0.0052	0.0023 ± 0.0003	0.0034 ± 0.0005	0.0325 ± 0.0046	0.0097 ± 0.0014	0.0450 ± 0.0064
T-Technical University	0.0071 ± 0.0010	0.0006 ± 0.0001	0.0058 ± 0.0008	0.0282 ± 0.0040	0.0226 ± 0.0032	0.0336 ± 0.0048
Vienna City Round About	0.0099 ± 0.0014	0.0003 ± 0.0000	0.0038 ± 0.0005	0.0312 ± 0.0044	0.0200 ± 0.0028	0.0288 ± 0.0041

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Table A45- Estimated Plane-wave Electric Field Transmitted into the Cornea of the Eye in V/m

Measurement Locations	FM broadcast	VHF TV	UHF TV	GSM 900	GSM 1800	UMTS (WCDMA/3G)
Abeka Junction	0.0119 ± 0.0017	0.0011 ± 0.0002	0.0193 ± 0.0028	0.0726 ± 0.0105	0.0627 ± 0.0090	0.0584 ± 0.00842
Airport Aviance	0.0083 ± 0.0012	0.0011 ± 0.0002	0.0190 ± 0.0027	0.1170 ± 0.0165	0.0673 ± 0.0095	0.0818 ± 0.01157
Comet Hills	0.0024 ± 0.0003	0.0006 ± 0.0001	0.0017 ± 0.0002	0.0001 ± 0.0000	0.0004 ± 0.0001	0.0001 ± 0.00001
Korle-Bu Teaching Hospital	0.0040 ± 0.0006	0.0011 ± 0.0002	0.0161 ± 0.0023	0.0536 ± 0.0075	0.0589 ± 0.0082	0.0134 ± 0.00188
McCarthy Hill	0.0228 ± 0.0032	0.0011 ± 0.0002	0.0071 ± 0.0010	0.1266 ± 0.0179	0.0734 ± 0.0103	0.0654 ± 0.00922
Rawlings Parka	0.0005 ± 0.0001	0.0002 ± 0.0000	0.0038 ± 0.0005	0.0681 ± 0.0097	0.0471 ± 0.0067	0.0534 ± 0.00760
Sakumono Total Filling Station	0.0228 ± 0.0033	0.0011 ± 0.0002	0.0146 ± 0.0021	0.0739 ± 0.0106	0.0637 ± 0.0091	0.0510 ± 0.00729
Tema Community One	0.0229 ± 0.0033	0.0012 ± 0.0002	0.0195 ± 0.0028	0.1511 ± 0.0215	0.0716 ± 0.0102	0.1906 ± 0.02707
Tema Roundabout	0.0030 ± 0.0004	0.0011 ± 0.0002	0.0209 ± 0.0030	0.0844 ± 0.0119	0.0767 ± 0.0108	0.0476 ± 0.00672
University Of Ghana	0.0782 ± 0.0112	0.0011 ± 0.0002	0.0193 ± 0.0028	0.1480 ± 0.0212	0.0716 ± 0.0103	0.2152 ± 0.03086
Adum	0.1030 ± 0.0146	0.0195 ± 0.0028	0.0231 ± 0.0033	0.0402 ± 0.0057	0.0459 ± 0.0065	0.0555 ± 0.00785
Airport Roundabout	0.0197 ± 0.0028	0.0028 ± 0.0004	0.0097 ± 0.0014	0.0402 ± 0.0057	0.0183 ± 0.0026	0.0522 ± 0.00746
Amakom Baba Yara Stadium	0.0499 ± 0.0072	0.0883 ± 0.0127	0.0356 ± 0.0051	0.0217 ± 0.0031	0.0147 ± 0.0021	0.0094 ± 0.00135
Bremang	0.0024 ± 0.0003	0.0024 ± 0.0003	0.0114 ± 0.0016	0.0420 ± 0.0060	0.0205 ± 0.0029	0.0296 ± 0.00420
Manhyia	0.1939 ± 0.0273	0.0019 ± 0.0003	0.0436 ± 0.0061	0.0660 ± 0.0093	0.0132 ± 0.0019	0.0447 ± 0.00630
Melcom	0.0168 ± 0.0024	0.0199 ± 0.0028	0.0281 ± 0.0040	0.0217 ± 0.0031	0.0147 ± 0.0021	0.0337 ± 0.00480
Prempeh College	0.0249 ± 0.0036	0.0020 ± 0.0003	0.0122 ± 0.0017	0.0516 ± 0.0074	0.0385 ± 0.0055	0.0458 ± 0.00655
Santasi Roundabout	0.0467 ± 0.0067	0.0199 ± 0.0028	0.0356 ± 0.0051	0.0576 ± 0.0082	0.0388 ± 0.0055	0.0293 ± 0.00417
UEW College of Technology	0.0075 ± 0.0011	0.0019 ± 0.0003	0.0098 ± 0.0014	0.0270 ± 0.0039	0.0152 ± 0.0022	0.0359 ± 0.00515
Wesley Girls SHS	0.0051 ± 0.0007	0.0019 ± 0.0003	0.0227 ± 0.0033	0.0332 ± 0.0048	0.0133 ± 0.0019	0.0474 ± 0.00683
Anaji Westline	0.0100 ± 0.0014	0.0007 ± 0.0001	0.0057 ± 0.0008	0.0667 ± 0.0094	0.0584 ± 0.0083	0.0451 ± 0.00639
DuPaul	0.0076 ± 0.0011	0.0007 ± 0.0001	0.0039 ± 0.0005	0.0333 ± 0.0047	0.0044 ± 0.0006	0.0555 ± 0.00783
Essipon Sekondi	0.0006 ± 0.0001	0.0007 ± 0.0001	0.0034 ± 0.0005	0.0333 ± 0.0047	0.0027 ± 0.0004	0.0405 ± 0.00573
Fort-Orange Sekondi	0.0052 ± 0.0007	0.0005 ± 0.0001	0.0323 ± 0.0046	0.0329 ± 0.0047	0.0521 ± 0.0074	0.0406 ± 0.00577
Galaxy	0.0058 ± 0.0008	0.0005 ± 0.0001	0.0057 ± 0.0008	0.0315 ± 0.0045	0.0233 ± 0.0033	0.0443 ± 0.00626
Habour	0.0060 ± 0.0009	0.0012 ± 0.0002	0.0037 ± 0.0005	0.0343 ± 0.0049	0.0096 ± 0.0014	0.0459 ± 0.00662
Lagos Town	0.0060 ± 0.0008	0.0007 ± 0.0001	0.0041 ± 0.0006	0.0306 ± 0.0043	0.0218 ± 0.0031	0.0464 ± 0.00657
Market Circle	0.0341 ± 0.0049	0.0022 ± 0.0003	0.0034 ± 0.0005	0.0323 ± 0.0046	0.0097 ± 0.0014	0.0453 ± 0.00648
T-Technical University	0.0067 ± 0.0009	0.0006 ± 0.0001	0.0057 ± 0.0008	0.0280 ± 0.0040	0.0227 ± 0.0032	0.0338 ± 0.00478
Vienna City Round About	0.0093 ± 0.0013	0.0003 ± 0.0000	0.0037 ± 0.0005	0.0310 ± 0.0044	0.0200 ± 0.0028	0.0290 ± 0.00409

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Table A46- Estimated SAR Values within Sclera in W/kg

Measurement Locations	FM broadcast	VHF TV	UHF TV	GSM 900	GSM 1800	UMTS (WCDMA/3G)
Abeka Junction	1.37E-07 ±1.98E-08	1.32E-09± 1.90E-10	3.96E-07 ± 5.71E-08	6.13E-06 ± 8.84E-07	6.16E-06 ± 8.88E-07	5.95E-06 ± 8.58E-07
Airport Aviance	6.80E-08 ±9.62E-09	1.11E-09± 1.57E-10	3.84E-07 ± 5.43E-08	1.59E-05 ± 2.25E-06	7.10E-06 ± 1.00E-06	1.17E-05 ± 1.65E-06
Comet Hills	5.93E-09 ±8.30E-10	3.29E-10± 4.61E-11	2.98E-09 ± 4.17E-10	1.15E-11 ± 1.61E-12	2.52E-10 ± 3.53E-11	1.76E-11 ± 2.46E-12
Korle-Bu Teaching Hospital	1.55E-08 ±2.17E-09	1.32E-09± 1.85E-10	2.74E-07 ± 3.84E-08	3.34E-06 ± 4.68E-07	5.44E-06 ± 7.62E-07	3.12E-07 ± 4.37E-08
McCarthy Hill	5.10E-07 ±7.19E-08	1.32E-09± 1.86E-10	5.50E-08 ± 7.76E-09	1.86E-05 ± 2.62E-06	8.43E-06 ± 1.19E-06	7.47E-06 ± 1.05E-06
Rawlings Park	2.19E-10 ±3.12E-11	3.66E-11± 5.21E-12	1.49E-08 ± 2.12E-09	5.39E-06 ± 7.68E-07	3.47E-06 ± 4.94E-07	4.97E-06 ± 7.08E-07
Sakumono Total Gas Station	5.10E-07 ±7.29E-08	1.32E-09± 1.89E-10	2.29E-07 ± 3.27E-08	6.35E-06 ± 9.08E-07	6.36E-06 ± 9.09E-07	4.53E-06 ± 6.48E-07
Tema Community One	5.14E-07 ±7.30E-08	1.32E-09± 1.87E-10	4.04E-07 ± 5.74E-08	2.66E-05 ± 3.78E-06	8.02E-06 ± 1.14E-06	6.34E-05 ± 9.00E-06
Tema Roundabout	8.99E-09 ±1.27E-09	1.32E-09± 1.86E-10	4.64E-07 ± 6.55E-08	8.29E-06 ± 1.17E-06	9.23E-06 ± 1.30E-06	3.96E-06 ± 5.59E-07
University Of Ghana	6.00E-06 ±8.60E-07	1.32E-09± 1.89E-10	3.96E-07 ± 5.68E-08	2.55E-05 ± 3.66E-06	8.02E-06 ± 1.15E-06	8.08E-05 ± 1.16E-05
Adum	1.04E-05 ±1.47E-06	3.77E-07± 5.33E-08	5.70E-07 ± 8.07E-08	1.89E-06 ± 2.67E-07	3.29E-06 ± 4.66E-07	5.37E-06 ± 7.60E-07
Airport Roundabout	3.80E-07 ±5.43E-08	7.69E-09± 1.10E-09	9.91E-08 ± 1.42E-08	1.89E-06 ± 2.70E-07	5.28E-07 ± 7.55E-08	4.75E-06 ± 6.79E-07
Baba Yara Stadium	2.45E-06 ±3.53E-07	7.76E-06± 1.12E-06	1.34E-06 ± 1.93E-07	5.46E-07 ± 7.86E-08	3.36E-07 ± 4.84E-08	1.56E-07 ± 2.25E-08
Bremang	5.49E-09 ±7.80E-10	5.72E-09± 8.12E-10	1.39E-07 ± 1.97E-08	2.05E-06 ± 2.91E-07	6.63E-07 ± 9.41E-08	1.53E-06 ± 2.17E-07
Manhyia	3.69E-05 ±5.20E-06	3.66E-09± 5.16E-10	2.02E-06 ± 2.85E-07	5.07E-06 ± 7.15E-07	2.75E-07 ± 3.88E-08	3.49E-06 ± 4.92E-07
Melcom	2.75E-07 ±3.92E-08	3.96E-07± 5.64E-08	8.44E-07 ± 1.20E-07	5.46E-07 ± 7.78E-08	3.36E-07 ± 4.79E-08	1.98E-06 ± 2.82E-07
Prempeh College	6.12E-07 ±8.75E-08	4.04E-09± 5.78E-10	1.59E-07 ± 2.27E-08	3.08E-06 ± 4.40E-07	2.31E-06 ± 3.30E-07	3.65E-06 ± 5.22E-07
Santasi Roundabout	2.14E-06 ±3.05E-07	3.96E-07± 5.64E-08	1.34E-06 ± 1.91E-07	3.85E-06 ± 5.48E-07	2.35E-06 ± 3.35E-07	1.50E-06 ± 2.14E-07
College of Technology	5.48E-08 ±7.86E-09	3.66E-09± 5.25E-10	1.03E-07 ± 1.48E-08	8.44E-07 ± 1.21E-07	3.64E-07 ± 5.22E-08	2.25E-06 ± 3.23E-07
Wesley Girls SHS	2.56E-08 ±3.69E-09	3.66E-09± 5.27E-10	5.50E-07 ± 7.92E-08	1.28E-06 ± 1.84E-07	2.79E-07 ± 4.02E-08	3.93E-06 ± 5.66E-07
Anaji Westline	9.68E-08 ±1.37E-08	4.48E-10± 6.34E-11	3.47E-08 ± 4.91E-09	5.18E-06 ± 7.33E-07	5.34E-06 ± 7.56E-07	3.55E-06 ± 5.03E-07
DuPaul	5.62E-08 ±7.92E-09	4.48E-10± 6.32E-11	1.57E-08 ± 2.21E-09	1.29E-06 ± 1.82E-07	3.05E-08 ± 4.30E-09	5.37E-06 ± 7.57E-07
Essipon Sekondi	3.16E-10 ±4.47E-11	5.86E-10± 8.29E-11	1.26E-08 ± 1.78E-09	1.29E-06 ± 1.83E-07	1.15E-08 ± 1.63E-09	2.86E-06 ± 4.05E-07
Fort-Orange Sekondi	2.56E-08 ±3.64E-09	3.29E-10± 4.67E-11	1.11E-06 ± 1.58E-07	1.26E-06 ± 1.79E-07	4.27E-06 ± 6.06E-07	2.88E-06 ± 4.09E-07
Galaxy	3.27E-08 ±4.62E-09	2.29E-10± 3.24E-11	3.47E-08 ± 4.91E-09	1.16E-06 ± 1.64E-07	8.49E-07 ± 1.20E-07	3.41E-06 ± 4.82E-07
Habour	3.48E-08 ±5.02E-09	1.32E-09± 1.90E-10	1.41E-08 ± 2.03E-09	1.37E-06 ± 1.98E-07	1.45E-07 ± 2.09E-08	3.68E-06 ± 5.31E-07
Lagos Town	3.48E-08 ±4.92E-09	4.48E-10± 6.34E-11	1.73E-08 ± .45E-09	1.09E-06 ± 1.54E-07	7.43E-07 ± 1.05E-07	3.76E-06 ± 5.32E-07
Market Circle	1.14E-06 ±1.63E-07	4.84E-09± 6.92E-10	1.19E-08 ± 1.70E-09	1.21E-06 ± 1.73E-07	1.48E-07 ± 2.12E-08	3.57E-06 ± 5.11E-07
T-Technical University	4.42E-08 ±6.25E-09	3.29E-10± 4.65E-11	3.47E-08 ± 4.91E-09	9.14E-07 ± 1.29E-07	8.06E-07 ± 1.14E-07	1.99E-06 ± 2.81E-07
Vienna City Roundabout	8.60E-08 ±1.21E-08	8.23E-11± 1.16E-11	1.49E-08 ± 2.10E-09	1.12E-06 ± 1.58E-07	6.31E-07 ± 8.90E-08	1.46E-06 ± 2.06E-07

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Table A47- Estimated SAR Values within Cornea in W/kg

Measurement Locations	FM broadcast	VHF TV	UHF TV	GSM 900	GSM 1800	UMTS (WCDMA/3G)
Abeka Junction	1.43E-07 ±2.06E-08	1.30E-09 ±1.87E-10	4.61E-07 ±6.65E-08	7.27E-06 ±1.05E-06	7.22E-06 ±1.04E-06	6.91E-0± 9.96E-07
Airport Aviance	6.96E-08 ±9.84E-09	1.30E-09 ±1.84E-10	4.47E-07 ±6.32E-08	1.89E-05 ±2.67E-06	8.32E-06 ±1.18E-06	1.36E-0± 1.92E-06
Comet Hills	5.82E-09 ±8.15E-10	3.87E-10 ±5.42E-11	3.58E-09 ±5.01E-10	1.38E-11 ±1.93E-12	2.94E-10 ±1.21E-11	2.03E-1± 2.84E-12
Korle-Bu Teaching Hospital	1.62E-08 ±2.27E-09	1.30E-09 ±1.82E-10	3.21E-07 ±4.49E-08	3.96E-06 ±5.54E-07	6.37E-06 ±8.92E-07	3.64E-0± 5.10E-08
McCarthy Hill	5.25E-07 ±7.40E-08	1.30E-09 ±1.83E-10	6.24E-08 ±8.80E-09	2.21E-05 ±3.12E-06	9.89E-06 ±1.39E-06	8.67E-0± 1.22E-06
Rawlings Park	2.53E-10 ±3.60E-11	4.30E-11 ±6.12E-12	1.79E-08 ±2.55E-09	6.40E-06 ±9.11E-07	4.07E-06 ±5.80E-07	5.78E-0± 8.23E-07
Sakumono Total Gas Statior	5.25E-07 ±7.51E-08	1.30E-09 ±1.86E-10	2.64E-07 ±3.78E-08	7.53E-06 ±1.08E-06	7.45E-06 ±1.07E-06	5.27E-0± 7.54E-07
Tema Community One	5.30E-07 ±7.53E-08	1.55E-09 ±2.20E-10	4.71E-07 ±6.69E-08	3.15E-05 ±4.47E-06	9.41E-06 ±1.34E-06	7.36E-0± 1.05E-05
Tema Roundabout	9.09E-09 ±1.28E-09	1.30E-09 ±1.84E-10	5.41E-07 ±7.64E-08	9.83E-06 ±1.39E-06	1.08E-05 ±1.52E-06	4.59E-0± 6.48E-07
University Of Ghana	6.18E-06 ±8.86E-07	1.30E-09 ±1.86E-10	4.61E-07 ±6.61E-08	3.02E-05 ±4.33E-06	9.41E-06 ±1.35E-06	9.38E-0± 1.35E-05
Adum	1.07E-05 ±1.51E-06	4.08E-07 ±5.77E-08	6.61E-07 ±9.35E-08	2.23E-06 ±3.16E-07	3.87E-06 ±5.48E-07	6.24E-0± 8.83E-07
Airport Roundabout	3.92E-07 ±5.61E-08	8.42E-09 ±1.20E-09	1.17E-07 ±1.67E-08	2.23E-06 ±3.19E-07	6.15E-07 ±8.79E-08	5.52E-0± 7.89E-07
Baba Yara Stadium	2.52E-06 ±3.63E-07	8.37E-06 ±1.21E-06	1.57E-06 ±2.26E-07	6.50E-07 ±9.36E-08	3.97E-07 ±5.72E-08	1.79E-0± 2.58E-08
Bremang	5.82E-09 ±8.26E-10	6.19E-09 ±8.79E-10	1.61E-07 ±2.29E-08	2.43E-06 ±3.45E-07	7.72E-07 ±1.10E-07	1.78E-0± 2.53E-07
Manhyia	3.80E-05 ±5.36E-06	3.88E-09 ±5.47E-10	2.35E-06 ±3.31E-07	6.01E-06 ±8.47E-07	3.20E-07 ±4.51E-08	4.05E-0± 5.71E-07
Melcom	2.85E-07 ±4.06E-08	4.25E-07 ±6.06E-08	9.78E-07 ±1.39E-07	6.50E-07 ±9.26E-08	3.97E-07 ±5.66E-08	2.30E-0± 3.28E-07
Prempeh College	6.26E-07 ±8.95E-08	4.30E-09 ±6.15E-10	1.84E-07 ±2.63E-08	3.67E-06 ±5.25E-07	2.72E-06 ±3.89E-07	4.25E-0± 6.08E-07
Santasi Roundabout	2.20E-06 ±3.13E-07	4.25E-07 ±6.05E-08	1.57E-06 ±2.24E-07	4.58E-06 ±6.52E-07	2.76E-06 ±3.93E-07	1.74E-0± 2.48E-07
College of Technology	5.68E-08 ±8.15E-09	3.88E-09 ±5.57E-10	1.19E-07 ±1.71E-08	1.01E-06 ±1.45E-07	4.24E-07 ±6.08E-08	2.61E-0± 3.75E-07
Wesley Girls SHS	2.63E-08 ±3.79E-09	3.88E-09 ±5.59E-10	6.38E-07 ±9.19E-08	1.52E-06 ±2.19E-07	3.25E-07 ±4.68E-08	4.55E-0± 6.55E-07
Anaji Westline	1.01E-07 ±1.43E-08	5.26E-10 ±7.45E-11	4.02E-08 ±5.69E-09	6.14E-06 ±8.69E-07	6.26E-06 ±8.86E-07	4.12E-0± 5.83E-07
DuPaul	5.84E-08 ±8.23E-09	5.26E-10 ±7.42E-11	1.88E-08 ±2.65E-09	1.53E-06 ±2.16E-07	3.55E-08 ±5.01E-09	6.24E-0± 8.80E-07
Essipon Sekondi	3.64E-10 ±5.15E-11	5.26E-10 ±7.44E-11	1.43E-08 ±2.02E-09	1.53E-06 ±2.16E-07	1.34E-08 ±1.90E-09	3.32E-0± 4.70E-07
Fort-Orange Sekondi	2.73E-08 ±3.88E-09	2.68E-10 ±3.81E-11	1.29E-06 ±1.83E-07	1.49E-06 ±2.12E-07	4.98E-06 ±7.07E-07	3.34E-0± 4.74E-07
Galaxy	3.40E-08 ±4.81E-09	2.68E-10 ±3.79E-11	4.02E-08 ±5.68E-09	1.37E-06 ±1.94E-07	9.97E-07 ±1.41E-07	3.98E-0± 5.63E-07
Habour	3.64E-08 ±5.25E-09	1.55E-09 ±2.24E-10	1.70E-08 ±2.45E-09	1.62E-06 ±2.34E-07	1.69E-07 ±2.44E-08	4.27E-0± 6.16E-07
Lagos Town	3.64E-08 ±5.15E-09	5.26E-10 ±7.44E-11	2.08E-08 ±2.94E-09	1.29E-06 ±1.83E-07	8.73E-07 ±1.24E-07	4.36E-0± 6.17E-07
Market Circle	1.17E-06 ±1.67E-07	5.20E-09 ±7.44E-10	1.43E-08 ±2.04E-09	1.44E-06 ±2.06E-07	1.73E-07 ±2.47E-08	4.16E-0± 5.95E-07
T-Technical University	4.54E-08 ±6.42E-09	3.87E-10 ±5.47E-11	4.02E-08 ±5.68E-09	1.08E-06 ±1.53E-07	9.46E-07 ±1.34E-07	2.31E-0± 3.27E-07
Vienna City Roundabout	8.74E-08 ±1.23E-08	9.67E-11 ±1.36E-11	1.70E-08 ±2.40E-09	1.33E-06 ±1.88E-07	7.34E-07 ±1.03E-07	1.70E-0± 2.40E-07

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Table A48- Estimated SAR Values within Dry Skin in W/kg

Measurement Locations	FM broadcast	VHF TV	UHF TV	GSM 900	GSM 1800	UMTS (WCDMA/3G)
Abeka Junction	8.14E-08±1.17E-08	8.77E-10 ±1.26E-10	3.32E-07 ±4.79E-08	5.47E-06 ±7.89E-07	5.57E-06 ±8.03E-07	5.34E-06 ±7.70E-07
Airport Aviance	3.97E-08±5.61E-09	7.47E-10 ±1.06E-10	3.20E-07 ±4.52E-08	1.42E-05 ±2.01E-06	6.43E-06 ±9.09E-07	1.05E-05 ±1.48E-06
Comet Hills	3.45E-09±4.83E-10	2.54E-10 ±3.56E-11	2.48E-09 ±3.47E-10	3.18E-11 ±4.45E-12	1.73E-10 ±2.42E-11	1.19E-11 ±1.67E-12
Korle-Bu Teaching Hospital	9.31E-09±1.30E-09	8.77E-10 ±1.23E-10	2.30E-07 ±3.22E-08	2.97E-06 ±4.16E-07	4.93E-06 ±6.90E-07	2.79E-07 ±3.91E-08
McCarthy Hill	3.00E-07±4.23E-08	8.77E-10 ±1.24E-10	4.50E-08 ±6.35E-09	1.66E-05 ±2.34E-06	7.65E-06 ±1.08E-06	6.72E-06 ±9.47E-07
Rawlings Park	1.58E-10±2.25E-11	2.08E-11 ±2.96E-12	1.27E-08 ±1.81E-09	4.81E-06 ±6.85E-07	3.15E-06 ±4.49E-07	4.47E-06 ±6.37E-07
Sakumono Total Gas Station	3.02E-07±4.32E-08	8.77E-10 ±1.25E-10	1.91E-07 ±2.73E-08	5.67E-06 ±8.11E-07	5.76E-06 ±8.24E-07	4.07E-06 ±5.78E-07
Tema Community One	3.02E-07±4.29E-08	8.77E-10 ±1.25E-10	3.38E-07 ±4.80E-08	2.37E-05 ±3.37E-06	7.27E-06 ±1.03E-06	5.69E-05 ±8.14E-06
Tema Roundabout	5.39E-09±7.61E-10	8.77E-10 ±1.24E-10	3.89E-07 ±5.49E-08	7.40E-06 ±1.04E-06	8.35E-06 ±1.18E-06	3.55E-06 ±5.01E-07
University Of Ghana	3.54E-06±5.08E-07	8.77E-10 ±1.26E-10	3.32E-07 ±4.76E-08	2.27E-05 ±3.26E-06	7.27E-06 ±1.04E-06	7.25E-05 ±1.04E-05
Aduni	6.14E-06±8.69E-07	2.58E-07 ±3.65E-08	4.75E-07 ±6.72E-08	1.68E-06 ±2.38E-07	2.99E-06 ±4.23E-07	4.83E-06 ±6.83E-07
Airport Roundabout	2.25E-07±3.22E-08	5.31E-09 ±7.59E-10	8.31E-08 ±1.19E-08	1.68E-06 ±2.40E-07	4.77E-07 ±6.82E-08	4.27E-06 ±6.10E-07
Baba Yara Stadium	1.44E-06±2.07E-07	5.29E-06 ±7.62E-07	1.13E-06 ±1.63E-07	4.88E-07 ±7.03E-08	3.05E-07 ±4.39E-08	1.39E-07 ±2.01E-08
Bremang	3.21E-09±4.56E-10	4.07E-09 ±5.78E-10	1.16E-07 ±1.65E-08	1.83E-06 ±2.60E-07	5.97E-07 ±8.48E-08	1.37E-06 ±1.95E-07
Manhyia	2.18E-05±3.07E-06	2.51E-09 ±3.54E-10	1.70E-06 ±2.40E-07	4.52E-06 ±6.37E-07	2.50E-07 ±3.53E-08	3.14E-06 ±4.43E-07
Melcom	1.64E-07±2.34E-08	2.70E-07 ±3.85E-08	7.07E-07 ±1.01E-07	4.88E-07 ±6.95E-08	3.05E-07 ±4.35E-08	1.78E-06 ±2.53E-07
Prempeh College	3.60E-07±5.15E-08	2.75E-09 ±3.93E-10	1.33E-07 ±1.90E-08	2.76E-06 ±3.95E-07	2.10E-06 ±3.00E-07	3.29E-06 ±4.71E-07
Santasi Roundabout	1.26E-06±1.79E-07	2.70E-07 ±3.84E-08	1.13E-06 ±1.61E-07	3.44E-06 ±4.90E-07	2.13E-06 ±3.03E-07	1.35E-06 ±1.92E-07
College of Technology	3.26E-08±4.68E-09	2.51E-09 ±3.60E-10	8.61E-08 ±1.24E-08	7.53E-07 ±1.08E-07	3.27E-07 ±4.69E-08	2.02E-06 ±2.89E-07
Wesley Girls SHS	1.53E-08±2.20E-09	2.51E-09 ±3.61E-10	4.61E-07 ±6.64E-08	1.15E-06 ±1.66E-07	2.53E-07 ±3.64E-08	3.53E-06 ±5.09E-07
Anaji Westline	5.72E-08±8.10E-09	3.32E-10 ±4.70E-11	2.90E-08 ±4.11E-09	4.61E-06 ±6.53E-07	4.85E-06 ±6.87E-07	3.19E-06 ±4.52E-07
DuPaul	3.33E-08±4.70E-09	3.32E-10 ±4.68E-11	1.33E-08 ±1.88E-09	1.15E-06 ±1.62E-07	2.81E-08 ±3.96E-09	4.81E-06 ±6.79E-07
Essipon Sekondi	2.16E-10±3.06E-11	3.32E-10 ±4.70E-11	1.04E-08 ±1.47E-09	1.15E-06 ±1.63E-07	1.04E-08 ±1.47E-09	2.57E-06 ±3.64E-07
Fort-Orange Sekondi	1.53E-08±2.17E-09	1.87E-10 ±2.66E-11	9.30E-07 ±1.32E-07	1.12E-06 ±1.59E-07	3.87E-06 ±5.50E-07	2.58E-06 ±3.67E-07
Galaxy	1.92E-08±2.71E-09	1.87E-10 ±2.64E-11	2.90E-08 ±4.10E-09	1.03E-06 ±1.46E-07	7.71E-07 ±1.09E-07	3.07E-06 ±4.34E-07
Habour	2.10E-08±3.03E-09	8.77E-10 ±1.26E-10	1.21E-08 ±1.74E-09	1.22E-06 ±1.76E-07	1.31E-07 ±1.89E-08	3.30E-06 ±4.67E-07
Lagos Town	2.10E-08±2.97E-09	3.32E-10 ±4.70E-11	1.45E-08 ±2.05E-09	9.73E-07 ±1.38E-07	6.76E-07 ±9.57E-08	3.38E-06 ±4.78E-07
Market Circle	6.73E-07±9.62E-08	3.24E-09 ±4.63E-10	1.04E-08 ±1.49E-09	1.08E-06 ±1.54E-07	1.33E-07 ±1.90E-08	3.20E-06 ±4.58E-07
T-Technical University	2.61E-08±3.69E-09	2.54E-10 ±3.59E-11	2.90E-08 ±4.10E-09	8.18E-07 ±1.16E-07	7.31E-07 ±1.03E-07	1.79E-06 ±2.53E-07
Vienna City Roundabout	5.04E-08±7.11E-09	8.30E-11 ±1.17E-11	1.21E-08 ±1.71E-09	1.00E-06 ±1.41E-07	5.72E-07 ±8.07E-08	1.32E-06 ±1.86E-07

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Table A49- Estimated SAR Values within Wet Skin in W/kg

Measurement Locations	FM broadcast	VHF TV	UHF TV	GSM 900	GSM 1800	UMTS (WCDMA/3G)
Abeka Junction	9.08E-08 ±1.31E-08	8.86E-10 ±1.28E-10	3.01E-07±4.34E-08	4.90E-06±7.07E-07	5.26E-06 ±7.58E-07	5.13E-06±7.40E-07
Airport Aviance	4.42E-08 ±6.25E-09	7.55E-10 ±1.07E-10	2.90E-07±4.10E-08	1.27E-05±1.80E-06	6.06E-06 ±8.57E-07	1.01E-05±1.43E-06
Comet Hills	3.95E-09 ±5.53E-10	2.57E-10 ±3.60E-11	2.40E-09±3.36E-10	3.10E-11±4.34E-12	1.80E-10 ±2.52E-11	1.27E-11±1.78E-12
Korle-Bu Teaching Hospital	1.04E-08 ±1.46E-09	8.86E-10 ±1.24E-10	2.08E-07±2.91E-08	2.66E-06±3.72E-07	4.63E-06 ±6.48E-07	2.67E-07±3.74E-08
McCarthy Hill	3.38E-07 ±4.77E-08	8.86E-10 ±1.25E-10	4.14E-08±5.84E-09	1.49E-05±2.10E-06	7.20E-06 ±1.02E-06	6.45E-06±9.09E-07
Rawlings Park	1.69E-10 ±2.41E-11	2.10E-11 ±2.99E-12	1.17E-08±1.67E-09	4.31E-06±6.14E-07	2.97E-06 ±4.23E-07	4.29E-06±6.11E-07
Sakumono Total Gas Station	3.38E-07 ±4.83E-08	8.86E-10 ±1.27E-10	1.74E-07±2.49E-08	5.08E-06±7.26E-07	5.43E-06 ±7.76E-07	3.92E-06±5.61E-07
Tema Community One	3.38E-07 ±4.80E-08	8.86E-10 ±1.26E-10	3.07E-07±4.36E-08	2.12E-05±3.01E-06	6.84E-06 ±9.71E-07	5.47E-05±7.77E-06
Tema Roundabout	6.09E-09 ±8.60E-10	8.86E-10 ±1.25E-10	3.54E-07±5.00E-08	6.62E-06±9.35E-07	7.88E-06 ±1.11E-06	3.41E-06±4.81E-07
University Of Ghana	3.96E-06 ±5.68E-07	8.86E-10 ±1.27E-10	3.01E-07±4.32E-08	2.04E-05±2.93E-06	6.84E-06 ±9.81E-07	6.97E-05±9.99E-06
Adum	6.87E-06 ±9.72E-07	2.61E-07 ±3.69E-08	4.31E-07±6.10E-08	1.50E-06±2.12E-07	2.82E-06 ±3.99E-07	4.64E-06±6.57E-07
Airport Roundabout	2.51E-07 ±3.59E-08	5.37E-09 ±7.68E-10	7.60E-08±1.09E-08	1.50E-06±2.15E-07	4.51E-07 ±6.45E-08	4.10E-06±5.86E-07
Baba Yara Stadium	1.61E-06 ±2.32E-07	5.34E-06 ±7.69E-07	1.02E-06±1.47E-07	4.36E-07±6.28E-08	2.89E-07 ±4.16E-08	1.35E-07±1.94E-08
Bremang	3.68E-09 ±5.23E-10	4.11E-09 ±5.84E-10	1.05E-07±1.49E-08	1.63E-06±2.31E-07	5.66E-07 ±8.04E-08	1.32E-06±1.87E-07
Manhyia	2.43E-05 ±3.43E-06	2.54E-09 ±3.58E-10	1.54E-06±2.17E-07	4.04E-06±5.70E-07	2.34E-07 ±3.30E-08	3.02E-06±4.26E-07
Melcom	1.82E-07 ±2.59E-08	2.72E-07 ±3.88E-08	6.38E-07±9.09E-08	4.36E-07±6.21E-08	2.89E-07 ±4.12E-08	1.70E-06±2.42E-07
Prempeh College	4.03E-07 ±5.76E-08	2.77E-09 ±3.96E-10	1.21E-07±1.73E-08	2.47E-06±3.53E-07	1.98E-06 ±2.83E-07	3.16E-06±4.52E-07
Santasi Roundabout	1.41E-06 ±2.01E-07	2.72E-07 ±3.87E-08	1.02E-06±1.45E-07	3.08E-06±4.39E-07	2.01E-06 ±2.86E-07	1.29E-06±1.84E-07
College of Technology	3.64E-08 ±5.22E-09	2.54E-09 ±3.64E-10	7.74E-08±1.11E-08	6.75E-07±9.69E-08	3.11E-07 ±4.46E-08	1.94E-06±2.78E-07
Wesley Girls SHS	1.69E-08 ±2.43E-09	2.54E-09 ±3.66E-10	4.15E-07±5.98E-08	1.03E-06±1.48E-07	2.37E-07 ±3.41E-08	3.39E-06±4.88E-07
Anaji Westline	6.43E-08 ±9.10E-09	3.35E-10 ±4.74E-11	2.63E-08±3.72E-09	4.13E-06±5.85E-07	4.56E-06 ±6.46E-07	3.07E-06±4.35E-07
DuPaul	3.72E-08 ±5.25E-09	3.35E-10 ±4.72E-11	1.23E-08±1.73E-09	1.03E-06±1.45E-07	2.60E-08 ±3.67E-09	4.63E-06±6.53E-07
Essipon Sekondi	2.30E-10 ±3.25E-11	3.35E-10 ±4.74E-11	9.58E-09±1.36E-09	1.03E-06±1.46E-07	9.48E-09 ±1.34E-09	2.46E-06±3.48E-07
Fort-Orange Sekondi	1.69E-08 ±2.40E-09	1.89E-10 ±2.68E-11	8.41E-07±1.19E-07	1.01E-06±1.43E-07	3.64E-06 ±5.17E-07	2.49E-06±3.54E-07
Galaxy	2.17E-08 ±3.07E-09	1.89E-10 ±2.67E-11	2.63E-08±3.72E-09	9.23E-07±1.31E-07	7.27E-07 ±1.03E-07	2.96E-06±4.19E-07
Habour	2.30E-08 ±3.32E-09	8.86E-10 ±1.28E-10	1.12E-08±1.62E-09	1.10E-06±1.59E-07	1.24E-07 ±1.79E-08	3.18E-06±4.59E-07
Lagos Town	2.30E-08 ±3.25E-09	3.35E-10 ±4.74E-11	1.34E-08±1.90E-09	8.71E-07±1.23E-07	6.33E-07 ±8.96E-08	3.24E-06±4.58E-07
Market Circle	7.56E-07 ±1.08E-07	3.28E-09 ±4.69E-10	9.08E-09±1.30E-09	9.72E-07±1.39E-07	1.27E-07 ±1.82E-08	3.08E-06±4.40E-07
T-Technical University	2.93E-08 ±4.14E-09	2.57E-10 ±3.63E-11	2.63E-08±3.72E-09	7.31E-07±1.03E-07	6.88E-07 ±9.73E-08	1.71E-06±2.42E-07
Vienna City Roundabout	5.69E-08 ±8.02E-09	8.39E-11 ±1.18E-11	1.12E-08±1.58E-09	8.91E-07±1.26E-07	5.36E-07 ±7.56E-08	1.26E-06±1.78E-07

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Table A50- Estimated Energy Values within Cornea in joules

Measurement Locations	FM broadcast	VHF TV	UHF TV	GSM 900	GSM 1800	UMTS (WCDMA/3G)
Abeka Junction	4.23E+02± 6.10E+01	3.08E+00 ± 4.44E-01	8.30E+02 ± 1.20E+02	1.13E+04 ±1.63E+03	8.08E+03 ±1.17E+03	6.94E+03 ±1.00E+03
Airport Aviance	2.06E+02± 2.91E+01	3.08E+00 ± 4.36E-01	8.04E+02 ± 1.14E+02	2.94E+04 ±4.16E+03	9.31E+03 ±1.32E+03	1.36E+04 ±1.92E+03
Comet Hills	1.72E+01± 2.41E+00	9.17E-01 ± 1.28E-01	6.44E+00 ± 9.02E-01	2.15E-02 ±3.01E-03	3.29E-01 ±4.61E-02	2.03E-02 ±2.84E-03
Korle-Bu Teaching Hospital	4.78E+01± 6.69E+00	3.08E+00 ± 4.31E-01	5.77E+02 ± 8.08E+01	6.17E+03 ±8.64E+02	7.13E+03 ±9.98E+02	3.65E+02 ±5.11E+01
McCarthy Hill	1.55E+03± 2.19E+02	3.08E+00 ± 4.34E-01	1.12E+02 ± 1.58E+01	3.44E+04 ±4.85E+03	1.11E+04 ±1.57E+03	8.70E+03 ±1.23E+03
Rawlings Park	7.47E-01 ± 1.06E-01	1.02E-01 ± 1.45E-02	3.22E+01 ± 4.59E+00	9.96E+03 ±1.42E+03	4.56E+03 ±6.49E+02	5.80E+03 ±8.26E+02
Sakumono Total Gas Station	1.55E+03± 2.22E+02	3.08E+00 ± 4.40E-01	4.75E+02 ± 6.79E+01	1.17E+04 ±1.67E+03	8.34E+03 ±1.19E+03	5.29E+03 ±7.56E+02
Tema Community One	1.57E+03± 2.23E+02	3.67E+00 ± 5.21E-01	8.47E+02 ± 1.20E+02	4.90E+04 ±6.96E+03	1.05E+04 ±1.49E+03	7.39E+04 ±1.05E+04
Tema Roundabout	2.69E+01± 3.80E+00	3.08E+00 ± 4.35E-01	9.73E+02 ± 1.37E+02	1.53E+04 ±2.16E+03	1.21E+04 ±1.71E+03	4.61E+03 ±6.51E+02
University Of Ghana	1.83E+04± 2.62E+03	3.08E+00 ± 4.42E-01	8.30E+02 ± 1.19E+02	4.70E+04 ±6.74E+03	1.05E+04 ±1.51E+03	9.42E+04 ±1.35E+04
Adum	3.17E+04± 4.49E+03	9.68E+02 ± 1.37E+02	1.19E+03 ± 1.68E+02	3.47E+03 ±4.91E+02	4.33E+03 ±6.13E+02	6.26E+03 ±8.86E+02
Airport Roundabout	1.16E+03± 1.66E+02	2.00E+01 ± 2.86E+00	2.10E+02 ± 3.00E+01	3.47E+03 ±4.96E+02	6.88E+02 ±9.84E+01	5.54E+03 ±7.92E+02
Baba Yara Stadium	7.44E+03± 1.07E+03	1.99E+04 ± 2.87E+03	2.82E+03 ± 4.06E+02	1.01E+03 ±1.45E+02	4.44E+02 ±6.39E+01	1.80E+02 ±2.59E+01
Bremang	1.72E+01± 2.44E+00	1.47E+01 ± 2.09E+00	2.90E+02 ± 4.12E+01	3.79E+03 ±5.38E+02	8.64E+02 ±1.23E+02	1.78E+03 ±2.53E+02
Manhyia	1.12E+05± 1.58E+04	9.19E+00 ± 1.30E+00	4.24E+03 ± 5.98E+02	9.35E+03 ±1.32E+03	3.58E+02 ±5.05E+01	4.06E+03 ±5.72E+02
Melcom	8.43E+02± 1.20E+02	1.01E+03 ± 1.44E+02	1.76E+03 ± 2.51E+02	1.01E+03 ±1.44E+02	4.44E+02 ±6.33E+01	2.31E+03 ±3.29E+02
Prempeh College	1.85E+03± 2.65E+02	1.02E+01 ± 1.46E+00	3.32E+02 ± 4.75E+01	5.72E+03 ±8.18E+02	3.05E+03 ±4.36E+02	4.27E+03 ±6.11E+02
Santasi Roundabout	6.51E+03± 9.27E+02	1.01E+03 ± 1.44E+02	2.82E+03 ± 4.02E+02	7.12E+03 ±1.0[illegible]E+03	3.09E+03 ±4.40E+02	1.75E+03 ±2.49E+02
College of Technology	1.68E+02± 2.41E+01	9.19E+00 ± 1.32E+00	2.14E+02 ± 3.07E+01	1.57E+03 ±2.25E+02	4.75E+02 ±6.82E+01	2.62E+03 ±3.76E+02
Wesley Girls SHS	7.77E+01± 1.12E+01	9.19E+00 ± 1.32E+00	1.15E+03 ± 1.66E+02	2.37E+03 ±3.41E+02	3.64E+02 ±5.24E+01	4.57E+03 ±6.58E+02
Anaji Westline	2.99E+02± 4.23E+01	1.25E+00 ± 1.77E-01	7.24E+01 ± 1.03E+01	9.55E+03 ±1.35E+03	7.01E+03 ±9.93E+02	4.14E+03 ±5.86E+02
DuPaul	1.73E+02± 2.44E+01	1.25E+00 ± 1.76E-01	3.39E+01 ± 4.78E+00	2.38E+03 ±3.36E+02	3.98E+01 ±5.61E+00	6.26E+03 ±8.83E+02
Essipon Sekondi	1.08E+00± 1.53E-01	1.25E+00 ± 1.77E-01	2.58E+01 ± 3.65E+00	2.38E+03 ±3.37E+02	1.50E+01 ±2.12E+00	3.34E+03 ±4.73E+02
Fort-Orange Sekondi	8.08E+01± 1.15E+01	6.37E-01 ± 9.05E-02	2.32E+03 ± 3.29E+02	2.32E+03 ±3.29E+02	5.58E+03 ±7.92E+02	3.35E+03 ±4.76E+02
Galaxy	1.00E+02± 1.41E+01	6.37E-01 ± 9.01E-02	7.24E+01 ± 1.02E+01	2.13E+03 ±3.01E+02	1.12E+03 ±1.58E+02	3.99E+03 ±5.64E+02
Habour	1.03E+02± 1.56E+01	3.67E+00 ± 5.29E-01	3.05E+01 ± 4.40E+00	2.53E+03 ±3.65E+02	1.89E+02 ±2.73E+01	4.28E+03 ±6.17E+02
Lagos Town	1.08E+02± 1.53E+01	1.25E+00 ± 1.77E-01	3.75E+01 ± 5.31E+00	2.01E+03 ±2.84E+02	9.77E+02 ±1.38E+02	4.38E+03 ±6.20E+02
Market Circle	3.47E+03± 4.96E+02	1.23E+01 ± 1.76E+00	2.58E+01 ± 3.69E+00	2.24E+03 ±3.20E+02	1.93E+02 ±2.76E+01	4.17E+03 ±5.96E+02
T-Technical University	1.34E+02± 1.89E+01	9.17E-01 ± 1.30E-01	7.24E+01 ± 1.02E+01	1.68E+03 ±2.38E+02	1.06E+03 ±1.50E+02	2.32E+03 ±3.28E+02
Vienna City Roundabout	2.58E+02± 3.64E+01	2.29E-01 ± .23E-02	3.05E+01 ± 4.30E+00	2.06E+03 ±2.90E+02	8.22E+02 ±1.16E+02	1.71E+03 ±2.41E+02

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Table A51- Estimated Energy Values within Sclera in joules

Measurement Locations	FM broadcast	VHF TV	UHF TV	GSM 900	GSM 1800	UMTS (WCDMA/3G)
Abeka Junction	5.33E+03±7.69E+02	4.40E+01± 5.77E-01	1.08E+04 ± 1.56E+03	1.47E+05 ± 2.12E+04	1.04E+05 ± 1.50E+04	8.95E+04 ± 1.29E+04
Airport Aviance	2.64E+03±3.73E+02	3.70E+01± 5.23E+00	1.05E+04 ± 1.48E+03	3.82E+05 ± 5.40E+04	1.20E+05 ± 1.70E+04	1.75E+05 ± 2.47E+04
Comet Hills	2.30E+02±3.22E+01	1.10E+01± 1.54E+00	8.14E+01 ± 1.14E+01	2.76E-01 ± 3.86E-02	4.28E+00 ± 5.99E-01	2.65E-01 ± 3.71E-02
Korle-Bu Teaching Hospital	6.01E+02±8.41E+01	4.40E+01± 6.16E+00	7.49E+03 ± 1.05E+03	8.00E+04 ± 1.12E+04	9.21E+04 ± 1.29E+04	4.69E+03 ± 6.57E+02
McCarthy Hill	1.98E+04±2.79E+03	4.40E+01± 6.20E+00	1.50E+03 ± 2.12E+02	4.46E+05 ± 6.29E+04	1.43E+05 ± 2.02E+04	1.12E+05 ± 1.58E+04
Rawlings Park	8.52E+00±1.21E+00	1.22E+00± 1.74E-01	4.07E+02 ± 5.80E+01	1.29E+05 ± 1.84E+04	5.88E+04 ± 8.37E+03	7.47E+04 ± 1.06E+04
Sakumono Total Gas Station	1.98E+04±2.83E+03	4.40E+01± 6.29E+00	6.26E+03 ± 8.95E+02	1.52E+05 ± 2.17E+04	1.08E+05 ± 1.54E+04	6.81E+04 ± 9.74E+03
Tema Community One	2.00E+04±2.84E+03	4.40E+01± 6.25E+00	1.10E+04 ± 1.56E+03	6.37E+05 ± 9.05E+04	1.36E+05 ± 1.93E+04	9.53E+05 ± 1.35E+05
Tema Roundabout	3.49E+02±4.93E+01	4.40E+01± 6.21E+00	1.27E+04 ± 1.79E+03	1.99E+05 ± 2.81E+04	1.56E+05 ± 2.20E+04	5.96E+04 ± 8.42E+03
University Of Ghana	2.33E+05±3.34E+04	4.40E+01± 6.31E+00	1.08E+04 ± 1.55E+03	6.11E+05 ± 8.76E+04	1.36E+05 ± 1.95E+04	1.21E+06 ± 1.74E+05
Adum	4.04E+05±5.72E+04	1.26E+04± 1.78E+03	1.56E+04 ± 2.21E+03	4.52E+04 ± 6.40E+03	5.58E+04 ± 7.90E+03	8.08E+04 ± 1.14E+04
Airport Roundabout	1.47E+04±2.10E+03	2.57E+02± 3.68E+01	2.71E+03 ± 3.88E+02	4.52E+04 ± 6.46E+03	8.95E+03 ± 1.28E+03	7.14E+04 ± 1.02E+04
Baba Yara Stadium	9.50E+04±1.37E+04	2.59E+05± 3.73E+04	3.67E+04 ± 5.28E+03	1.31E+04 ± 1.89E+03	5.70E+03 ± 8.21E+02	2.34E+03 ± 3.37E+02
Bremang	2.13E+02±3.02E+01	1.91E+02± 2.71E+01	3.79E+03 ± 5.38E+02	4.91E+04 ± 6.97E+03	1.12E+04 ± 1.59E+03	2.31E+04 ± 3.28E+03
Manhyia	1.43E+06±2.02E+05	1.22E+02± 1.72E+01	5.53E+04 ± 7.80E+03	1.21E+05 ± 1.71E+04	4.66E+03 ± 6.57E+02	5.25E+04 ± 7.40E+03
Melcom	1.07E+04±1.52E+03	1.32E+04± 1.88E+03	2.30E+04 ± 3.28E+03	1.31E+04 ± 1.87E+03	5.70E+03 ± 8.12E+02	2.97E+04 ± 4.23E+03
Prempeh College	2.38E+04±3.40E+03	1.35E+02± 1.93E+01	4.33E+03 ± 6.19E+02	7.39E+04 ± 1.06E+04	3.92E+04 ± 5.61E+03	5.49E+04 ± 7.85E+03
Santasi Roundabout	8.32E+04±1.18E+04	1.32E+04± 1.88E+03	3.67E+04 ± 5.23E+03	9.24E+04 ± 1.32E+04	3.98E+04 ± 5.67E+03	2.26E+04 ± 3.22E+03
College of Technology	2.13E+03±3.06E+02	1.22E+02± 1.75E+01	2.82E+03 ± 4.05E+02	2.02E+04 ± 2.90E+03	6.18E+03 ± 8.87E+02	3.38E+04 ± 4.85E+03
Wesley Girls SHS	9.94E+02±1.43E+02	1.22E+02± 1.76E+01	1.50E+04 ± 2.16E+03	3.07E+04 ± 4.42E+03	4.73E+03 ± 6.81E+02	5.91E+04 ± 8.51E+03
Anaji Westline	3.76E+03±5.32E+02	1.50E+01± 2.12E+00	9.48E+02 ± 1.34E+02	1.24E+05 ± 1.76E+04	9.05E+04 ± 1.28E+04	5.34E+04 ± 7.56E+03
DuPaul	2.18E+03±3.07E+02	1.50E+01± 2.12E+00	4.29E+02 ± 6.05E+01	3.09E+04 ± 4.36E+03	5.17E+02 ± 7.29E+01	8.08E+04 ± 1.14E+04
Essipon Sekondi	1.23E+01±1.74E+00	1.96E+01± 2.77E+00	3.45E+02 ± 4.88E+01	3.09E+04 ± 4.37E+03	1.95E+02 ± 2.76E+01	4.31E+04 ± 6.10E+03
Fort-Orange Sekondi	9.94E+02±1.41E+02	1.10E+01± 1.56E+00	3.03E+04 ± 4.30E+03	3.02E+04 ± 4.29E+03	7.23E+04 ± 1.03E+04	4.33E+04 ± 6.15E+03
Galaxy	1.27E+03±1.80E+02	7.65E+00± 1.08E+00	9.48E+02 ± 1.34E+02	2.77E+04 ± 3.92E+03	1.44E+04 ± 2.04E+03	5.13E+04 ± 7.25E+03
Habour	1.35E+03±1.95E+02	4.40E+01± 6.34E+00	3.86E+02 ± 5.57E+01	3.28E+04 ± 4.73E+03	2.46E+03 ± 3.55E+02	5.54E+04 ± 7.99E+03
Lagos Town	1.35E+03±1.91E+02	1.50E+01± 2.12E+00	4.74E+02 ± 6.71E+01	2.61E+04 ± 3.69E+03	1.26E+04 ± 1.78E+03	5.66E+04 ± 8.01E+03
Market Circle	4.44E+04±6.35E+03	1.62E+02± 2.32E+01	3.26E+02 ± 4.66E+01	2.91E+04 ± 4.16E+03	2.52E+03 ± 3.60E+02	5.37E+04 ± 7.68E+03
T-Technical University	1.72E+03±2.43E+02	1.10E+01± 1.56E+00	9.48E+02 ± 1.34E+02	2.19E+04 ± 3.10E+03	1.37E+04 ± 1.94E+03	2.99E+04 ± 4.23E+03
Vienna City Roundabout	3.34E+03±4.71E+02	2.75E+00± 3.88E-01	4.07E+02 ± 5.74E+01	2.68E+04 ± 3.78E+03	1.07E+04 ± 1.51E+03	2.20E+04 ± 3.10E+03

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Table A52- Estimated Energy Values within Dry Skin in joules

Measurement Locations	FM broadcast	VHF TV	UHF TV	GSM 900	GSM 1800	UMTS (WCDMA/3G)
Abeka Junction	6.92E+06±9.98E+05	4.78E+04± 6.89E+03	1.08E+07 ± 1.56E+06	1.44E+08± 2.08E+07	1.01E+08 ± 1.46E+07	8.71E+07 ± 1.26E+07
Airport Aviance	3.38E+06± 4.78E+05	4.07E+04± 5.75E+03	1.04E+07 ± 1.47E+06	3.74E+08± 5.29E+07	1.17E+08 ± 1.65E+07	1.71E+08 ± 2.42E+07
Comet Hills	2.94E+05± 4.12E+04	1.38E+04± 1.93E+03	8.02E+04 ± 1.12E+04	8.35E+02± 1.17E+02	3.15E+03 ± 4.41E+02	1.95E+02 ± 2.73E+01
Korle-Bu Teaching Hospital	7.92E+05± 1.11E+05	4.78E+04± 6.69E+03	7.44E+06 ± 1.04E+06	7.82E+07± 1.09E+07	8.97E+07 ± 1.26E+07	4.56E+06 ± 6.38E+05
McCarthy Hill	2.55E+07± 3.60E+06	4.78E+04± 6.74E+03	1.46E+06 ± 2.06E+05	4.37E+08± 6.16E+07	1.39E+08 ± 1.96E+07	1.09E+08 ± 1.54E+07
Rawlings Park	1.35E+04± 1.92E+03	1.13E+03± 1.61E+02	4.11E+05 ± 5.85E+04	1.26E+08± 1.79E+07	5.74E+07 ± 8.17E+06	7.29E+07 ± 1.04E+07
Sakumono Total Gas Station	2.57E+07± 3.68E+06	4.78E+04± 6.84E+03	6.20E+06 ± 8.87E+05	1.49E+08± 2.13E+07	1.05E+08 ± 1.50E+07	6.64E+07 ± 9.50E+06
Tema Community One	2.57E+07± 3.65E+06	4.78E+04± 6.79E+03	1.10E+07 ± 1.56E+06	6.24E+08± 8.86E+07	1.32E+08 ± 1.87E+07	9.28E+08 ± 1.32E+08
Tema Roundabout	4.59E+05± 6.48E+04	4.78E+04± 6.75E+03	1.26E+07 ± 1.78E+06	1.94E+08± 2.74E+07	1.52E+08 ± 2.15E+07	5.78E+07 ± 8.16E+06
University Of Ghana	3.01E+08± 4.32E+07	4.78E+04± 6.85E+03	1.08E+07 ± 1.55E+06	5.98E+08± 8.58E+07	1.32E+08 ± 1.89E+07	1.18E+09 ± 1.69E+08
Adum	5.22E+08± 7.39E+07	1.41E+07± 2.00E+06	1.54E+07 ± 2.18E+06	4.42E+07± 6.25E+06	5.44E+07 ± 7.70E+06	7.87E+07 ± 1.11E+07
Airport Roundabout	1.91E+07± 2.73E+06	2.89E+05± 4.13E+04	2.69E+06 ± 3.85E+05	4.42E+07± 6.32E+06	8.68E+06 ± 1.24E+06	6.96E+07 ± 9.95E+06
Baba Yara Stadium	1.22E+08± 1.76E+07	2.88E+08± 4.15E+07	3.66E+07 ± 5.27E+06	1.28E+07± 1.84E+06	5.55E+06 ± 7.99E+05	2.27E+06 ± 3.27E+05
Bremang	2.73E+05± 3.88E+04	2.22E+05± 3.15E+04	3.75E+06 ± 5.33E+05	4.81E+07± 6.83E+06	1.09E+07 ± 1.55E+06	2.24E+07 ± 3.18E+06
Manhyia	1.85E+09± 2.61E+08	1.37E+05± 1.93E+04	5.49E+07 ± 7.74E+06	1.19E+08± 1.68E+07	4.55E+06 ± 6.42E+05	5.12E+07 ± 7.22E+06
Melcom	1.39E+07± 1.98E+06	1.47E+07± 2.09E+06	2.29E+07 ± 3.26E+06	1.28E+07± 1.82E+06	5.55E+06 ± 7.91E+05	2.90E+07 ± 4.13E+06
Prempeh College	3.06E+07± 4.38E+06	1.49E+05± 2.13E+04	4.29E+06 ± 6.13E+05	7.25E+07± 1.04E+07	3.83E+07 ± 5.48E+06	5.36E+07 ± 7.66E+06
Santasi Roundabout	1.07E+08± 1.52E+07	1.47E+07± 2.09E+06	3.66E+07 ± 5.21E+06	9.04E+07± 1.29E+07	3.88E+07 ± 5.53E+06	2.20E+07 ± 3.13E+06
College of Technology	2.77E+06± 3.97E+05	1.37E+05± 1.97E+04	2.79E+06 ± 4.00E+05	1.98E+07± 2.84E+06	5.96E+06 ± 8.55E+05	3.29E+07 ± 4.72E+06
Wesley Girls SHS	1.30E+06± 1.87E+05	1.37E+05± 1.97E+04	1.49E+07 ± 2.15E+06	3.02E+07± 4.35E+06	4.61E+06 ± 6.64E+05	5.76E+07 ± 8.29E+06
Anaji Westline	4.87E+06± 6.90E+05	1.81E+04± 2.56E+03	9.39E+05 ± 1.33E+05	1.21E+08± 1.71E+07	8.83E+07 ± 1.25E+07	5.20E+07 ± 7.36E+06
DuPaul	2.83E+06± 3.99E+05	1.81E+04± 2.55E+03	4.30E+05 ± 6.06E+04	3.03E+07± 4.27E+06	5.12E+05 ± 7.22E+04	7.85E+07 ± 1.11E+07
Essipon Sekondi	1.83E+04± 2.59E+03	1.81E+04± 2.56E+03	3.38E+05 ± 4.78E+04	3.03E+07± 4.29E+06	1.89E+05 ± 2.67E+04	4.19E+07 ± 5.93E+06
Fort-Orange Sekondi	1.30E+06± 1.85E+05	1.02E+04± 1.45E+03	3.01E+07 ± 4.27E+06	2.95E+07± 4.19E+06	7.04E+07 ± 1.00E+07	4.21E+07 ± 5.98E+06
Galaxy	1.63E+06± 2.30E+05	1.02E+04± 1.44E+03	9.39E+05 ± 1.33E+05	2.71E+07± 3.83E+06	1.40E+07 ± 1.98E+06	5.00E+07 ± 7.07E+06
Habour	1.78E+06± 2.57E+05	4.78E+04± 6.89E+03	3.92E+05 ± 5.65E+04	3.21E+07± 4.63E+06	2.38E+06 ± 3.43E+05	5.38E+07 ± 7.76E+06
Lagos Town	1.78E+06± 2.52E+05	1.81E+04± 2.56E+03	4.70E+05 ± 6.65E+04	2.56E+07± 3.62E+06	1.23E+07 ± 1.74E+06	5.51E+07 ± 7.80E+06
Market Circle	5.72E+07± 8.18E+06	1.77E+05± 2.53E+04	3.38E+05 ± 4.83E+04	2.84E+07± 4.06E+06	2.42E+06 ± 3.46E+05	5.22E+07 ± 7.46E+06
T-Technical University	2.22E+06± 3.14E+05	1.38E+04± 1.95E+03	9.39E+05 ± 1.33E+05	2.15E+07± 3.04E+06	1.33E+07 ± 1.88E+06	2.91E+07 ± 4.11E+06
Vienna City Roundabout	4.29E+06± 6.05E+05	4.52E+03± 6.37E+02	3.92E+05 ± 5.53E+04	2.63E+07± 3.71E+06	1.04E+07 ± 1.47E+06	2.14E+07 ± 3.02E+06

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Table A53- Estimated Energy Values within Wet Skin in joules

Measurement Locations	FM broadcast	VHF TV	UHF TV	GSM 900	GSM 1800	UMTS (WCDMA/3G)
Abeka Junction	6.51E+06± 9.39E+05	4.77E+04± 6.88E+03	1.10E+07± 1.59E+06	1.47E+08± 2.12E+07	1.04E+08 ± 1.50E+07	8.85E+07 ±1.28E+07
Airport Aviance	3.17E+06± 4.48E+05	4.06E+04± 5.74E+03	1.06E+07± 1.50E+06	3.82E+08± 5.40E+07	1.19E+08 ± 1.68E+07	1.74E+08 ± 2.46E+07
Comet Hills	2.84E+05± 3.98E+04	1.38E+04± 1.93E+03	8.76E+04± 1.23E+04	9.31E+02± 1.30E+02	3.55E+03 ± 4.97E+02	2.20E+02 ± 3.08E+01
Korle-Bu Teaching Hospital	7.45E+05± 1.04E+05	4.77E+04± 6.68E+03	7.60E+06± 1.06E+06	7.99E+07± 1.12E+07	9.12E+07 ± 1.28E+07	4.62E+06 ± 6.47E+05
McCarthy Hill	2.42E+07± 3.41E+06	4.77E+04± 6.73E+03	1.51E+06± 2.13E+05	4.47E+08± 6.30E+07	1.42E+08 ± 2.00E+07	1.11E+08 ± 1.57E+07
Rawlings Park	1.21E+04± 1.72E+03	1.13E+03± 1.61E+02	4.28E+05± 6.09E+04	1.29E+08± 1.84E+07	5.84E+07 ± 8.32E+06	7.41E+07 ± 1.06E+07
Sakumono Total Gas Station	2.42E+07± 3.46E+06	4.77E+04± 6.82E+03	6.37E+06± 9.11E+05	1.52E+08± 2.17E+07	1.07E+08 ± 1.53E+07	6.76E+07 ± 9.67E+06
Tema Community One	2.42E+07± 3.44E+06	4.77E+04± 6.77E+03	1.12E+07± 1.59E+06	6.37E+08± 9.05E+07	1.35E+08 ± 1.92E+07	9.44E+08 ± 1.34E+08
Tema Roundabout	4.37E+05± 6.17E+04	4.77E+04± 6.74E+03	1.29E+07± 1.82E+06	1.99E+08± 2.81E+07	1.55E+08 ± 2.19E+07	5.89E+07 ± 8.32E+06
University Of Ghana	2.84E+08± 4.07E+07	4.77E+04± 6.84E+03	1.10E+07± 1.58E+06	6.11E+08± 8.76E+07	1.35E+08 ± 1.94E+07	1.20E+09 ± 1.72E+08
Adum	4.93E+08± 6.98E+07	1.40E+07± 1.98E+06	1.58E+07± 2.24E+06	4.51E+07± 6.38E+06	5.55E+07 ± 7.85E+06	8.01E+07 ± 1.13E+07
Airport Roundabout	1.80E+07± 2.57E+06	2.89E+05± 4.13E+04	2.78E+06± 3.98E+05	4.51E+07± 6.45E+06	8.88E+06 ± 1.27E+06	7.08E+07 ± 1.01E+07
Baba Yara Stadium	1.16E+08± 1.67E+07	2.87E+08± 4.13E+07	3.73E+07± 5.37E+06	1.31E+07± 1.89E+06	5.68E+06 ± 8.18E+05	2.33E+06 ± 3.36E+05
Bremang	2.64E+05± 3.75E+04	2.21E+05± 3.14E+04	3.85E+06± 5.47E+05	4.90E+07± 6.96E+06	1.11E+07 ± 1.58E+06	2.28E+07 ± 3.24E+06
Manhyia	1.75E+09± 2.47E+08	1.37E+05± 1.93E+04	5.61E+07± 7.91E+06	1.21E+08± 1.71E+07	4.60E+06 ± 6.49E+05	5.21E+07 ± 7.35E+06
Melcom	1.31E+07± 1.87E+06	1.47E+07± 2.09E+06	2.33E+07± 3.32E+06	1.31E+07± 1.87E+06	5.68E+06 ± 8.09E+05	2.94E+07 ± 4.19E+06
Prempeh College	2.89E+07± 4.13E+06	1.49E+05± 2.13E+04	4.42E+06± 6.32E+05	7.41E+07± 1.06E+07	3.90E+07 ± 5.58E+06	5.45E+07 ± 7.79E+06
Santasi Roundabout	1.01E+08± 1.44E+07	1.47E+07± 2.09E+06	3.73E+07± 5.31E+06	9.24E+07± 1.32E+07	3.95E+07 ± 5.62E+06	2.23E+07 ± 3.18E+06
College of Technology	2.61E+06± 3.75E+05	1.37E+05± 1.97E+04	2.83E+06± 4.06E+05	2.03E+07± 2.91E+06	6.12E+06 ± 8.78E+05	3.36E+07 ± 4.82E+06
Wesley Girls SHS	1.21E+06± 1.74E+05	1.37E+05± 1.97E+04	1.52E+07± 2.19E+06	3.08E+07± 4.44E+06	4.67E+06 ± 6.72E+05	5.85E+07 ± 8.42E+06
Anaji Westline	4.61E+06± 6.53E+05	1.81E+04± 2.56E+03	9.63E+05± 1.36E+05	1.24E+08± 1.76E+07	8.98E+07 ± 1.27E+07	5.29E+07 ± 7.49E+06
DuPaul	2.67E+06± 3.76E+05	1.81E+04± 2.55E+03	4.49E+05± 6.33E+04	3.10E+07± 4.37E+06	5.12E+05 ± 7.22E+04	7.98E+07 ± 1.13E+07
Essipon Sekondi	1.65E+04± 2.33E+03	1.81E+04± 2.56E+03	3.50E+05± 4.95E+04	3.10E+07± 4.39E+06	1.87E+05 ± 2.65E+04	4.25E+07 ± 6.01E+06
Fort-Orange Sekondi	1.21E+06± 1.72E+05	1.02E+04± 1.45E+03	3.07E+07± 4.36E+06	3.02E+07± 4.29E+06	7.16E+07 ± 1.02E+07	4.29E+07 ± 6.09E+06
Galaxy	1.56E+06± 2.21E+05	1.02E+04± 1.44E+03	9.63E+05± 1.36E+05	2.77E+07± 3.92E+06	1.43E+07 ± 2.02E+06	5.10E+07 ± 7.21E+06
Habour	1.65E+06± 2.38E+05	4.77E+04± 6.88E+03	4.08E+05± 5.88E+04	3.29E+07± 4.74E+06	2.45E+06 ± 3.53E+05	5.49E+07 ± 7.92E+06
Lagos Town	1.65E+06± 2.33E+05	1.81E+04± 2.56E+03	4.91E+05± 6.95E+04	2.61E+07± 3.69E+06	1.25E+07 ± 1.77E+06	5.60E+07 ± 7.92E+06
Market Circle	5.42E+07± 7.75E+06	1.76E+05± 2.52E+04	3.32E+05± 4.75E+04	2.92E+07± 4.18E+06	2.49E+06 ± 3.56E+05	5.31E+07 ± 7.59E+06
T-Technical University	2.10E+06± 2.97E+05	1.38E+04± 1.95E+03	9.63E+05± 1.36E+05	2.19E+07± 3.10E+06	1.35E+07 ± 1.91E+06	2.96E+07 ± 4.19E+06
Vienna City Roundabout	4.08E+06± 5.75E+05	4.52E+03± 6.37E+02	4.08E+05± 5.75E+04	2.68E+07± 3.78E+06	1.06E+07 ± 1.49E+06	2.18E+07 ± 3.07E+06

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Table A54- Uncertainty Associated with the Electric Field Measurement

Uncertainty sources	Type	Estimate (%)	Probability distribution	Divisor	Standard uncertainty (%)
Spectrum Analyzer					
Amplitude Accuracy	B	2.5	Rectangular	2.00	1.43
Resolution Bandwidth (200kHz)	B	0.10	Normal	2.00	0.05
Device-Under-Test					
Mismatch (Analyzer and Antenna)	B	2.10	U-shape	1.41	1.49
Antenna Calibration Factors	B	2.00	Normal	2.00	1.00
Cable Correction Factor	B	1.10	Rectangular	1.73	0.63
Measurement Repeatability	A	0.10	Normal	2.00	0.05
Measurement uncertainty					
Combined Uncertainty (%)					4.65
Coverage Factor					1.95
Expanded Uncertainty (%)					9.07

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Table A55- Statistical Analysis on Electric Field Strength Levels

Parameters	FM broadcast	VHF TV	UHF TV	GSM 900	GSM 1800	UMTS (WCDMA/3G)
	Electric field strength/Vm^{-1}					
Standard Deviation	0.1416	0.0040	0.0333	0.2003	0.0922	0.2912
Sample Mean	0.1098	0.0059	0.0599	0.3696	0.2334	0.3198
Minimum	0.0031	0.0055	0.0017	0.0059	0.0051	0.0052
Maximum	0.4768	0.0058	0.0933	0.6514	0.3209	0.8924
Error of Mean	0.0448	0.0005	0.0105	0.0633	0.0292	0.0921

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Appendix B

Publication

Azah, C. K., Amoako, J. K and Sam, F. (2018). Spatial distribution of electric field strength at a teaching hospital premises due to transmissions between 87.5 MHz and 2.6 GHz. *Radiat. Prot. Dosim.*, *183*(3), 348-354. https:/doi.org/10.1093/rpd/ncy124

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