UNIVERSITY OF CAPE COAST

ASSESSMENT OF PUBLIC EXPOSURE TO RADIOFREQUENCY RADIATIONS FROM MOBILE PHONE BASE STATIONS AND HANDSETS

BY

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THESIS SUBMITTED TO THE DEPARTMENT OF PHYSICS OF THE SCHOOL OF PHYSICAL SCIENCES, UNIVERSITY OF CAPE COAST IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE AWARD OF DOCTOR OF PHILOSOPHY DEGREE IN PHYSICS

JULY, 2009

DECLARATION

Candidate's Declaration

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

Candidate's Signature..Date: 25-08-2010

Name: Joseph Kwabena Amoako.

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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ABSTRACT

This thesis reports the results of radio frequency exposure level in the vicinity of fifty mobile phone base stations in Ghana. The measurements showed that a power density variation of as low as $0.01\mu W/m^2$ to as high as $10\mu W/m^2$ for the frequency of 900 MHz. At a transmission frequency of 1800MHz, the variations of power densities were from $0.01\mu W/m^2$ to $100\mu W/m^2$. The results generally showed that level of compliance with ICNIRP limit was about 0.01%. These results are much higher than results in other countries where there are radio frequency safety regulations in place for the installation of RF antennae.

The temperature rise in human head caused by absorbed power in the form of SAR from mobile phones is computed using bio-heat equation approach. The SAR was computed for fifty mobile phone handsets that radiate at 900MHz and 1800MHz. The temperature rise in the human head were calculated and the results show that average SAR values of 0.42W/kg, 0.98W/kg, 1.7W/kg, and 1.94W/kg resulted in temperature rise of 0.14°C, 0.15°C, 0.17°C and 0.18°C respectively after 10min. Using PMMA phantom the temperature changes in the human head at different frequencies there was 0.19°C change over the initial 20°C for the 1800MHz and at the 900 MHz the temperature change was 0.18°C. The results showed that PMMA phantom can be used to estimate temperature changes within the human head.

The results presented in this work will help in the further development of criteria for exposure guidelines, and technique developed may be used to assess temperature rises in the head associated with SARs for different types of RF exposure.

ACKNOWLEDGEMENTS

No project of this scope is the product of one person. I am honoured to have some of my colleagues and collaborators in Radiation Protection Institute making significant contributions towards this work.

Thank you, Prof. J. J. Fletcher and Dr. E. O. Darko, my supervisors for reading, analyzing and commenting on this thesis. This work is far better because of your contributions.

I also extend special thanks to Prof Cyril Schandorf, Prof. Akaho for their constant encouragement. Further acknowledgement goes to Mr. E. Ampomah-Amoako of GHARR I reactor centre for offering help in the development of computer programmes.

Very special thanks also goes to my suffering wife and children, Emelia, Olga, Joel and Nathan all of whom lived with mostly absent husband-father during the period of this work.

Additionally, my sincerest acknowledgement goes to the mobile telephone companies in Ghana-MTN, TIGO, GT and Kasapa for giving me access to some of their cell sites to take measurements.

Finally, many thanks to National Communication Authority (NCA) for making available relevant data on the Mobile Phone Companies in Ghana and Ms Dora Asamoah for editing final edition of this thesis.

DEDICATION

To my dear mum, Nancy Dukwaa Ayisi for her singular effort and dedication to ensure that I am educated. I dedicate this work to you and all single mothers.

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CHAPTER ONE

INTRODUCTION

Background

Ghana has since the early nineteen ninety's experienced more developments in the telecommunication and information technology sector. The number of payphones has increased from 480 in 1997, to over 3500 in 2000 (GT, 2001). Further over fifty Internet Service Providers (ISPs) have been licensed since 1996.

Improvement in the socio-economic environment has led to increase in the private investments in the telecommunication and the information technology sector.

At present there are four major operators in the telecommunication sector operating mobile phone networks. These are Kasapa, MTN company, Ghana Telecom and Millicom. There has been increase in the number of mobile phones and their base stations in Ghana in recent times. The number of payphones rose from 480 in 1997 to over 3,500 in 2000 (NCA, 2001). By the beginning of the year 2001, Ghana Telecom increased the number of fixed lines in the country from a meagre 78,000 in 1997 to over 220,000 lines in 2001. In December 2006, the number of fixed lines in Ghana was 360,375(NCA, 2007).

Statistics as at December 2006 (NCA, 2007) put the number of mobile phone subscribers in Ghana to over 3.4 million for all the four networks operating in Ghana. This is made up of MTN, 2,855, 467; Mobitel (tiGO), 1,546,721; GT-Onetouch, 877,106 and Kasapa, 200,104. Recent statistics put the number of mobile phone users as at March 2009 to be about 12.3 million (NCA, 2009). The corresponding number of cell sites is 3091 across the country. In Ghana, cellular phones operate within the frequency band of 900MHz and 1800 MHz.

For easy and rapid deployment of communication there has been the increased use of wireless technologies. These technologies utilize frequencies within the electromagnetic spectrum which require the use of different antennas. The increased use of this spectrum has led to the proliferation of antennas.

Source of Electromagnetic Fields

Electromagnetic radiation is the transportation of energy through space. The electromagnetic spectrum spans a very large range of frequencies – more than 15 orders of magnitude, and ranges from below power-frequency fields to ionising radiation. This spectrum can be divided into three broad bands based on their frequency or wavelength: electromagnetic fields and radiation (0 hertz (Hz) to 300 gigahertz (GHz); infrared and optical radiation; and ionising radiation. Electromagnetic fields and radiation are further broken down into: extremely-low-frequency (ELF) EMF (3 to 3 000 Hz); radio frequencies, which range from the very low frequencies of television sets and visual display units (about 30 kHz) to the high frequencies of FM radio (about 300 MHz); and microwaves, which are at the high end of this spectrum (up to 300 GHz). Power-frequency EMF falls into the ELF range of the spectrum; the frequency depends on the power source. Power systems operate at frequencies of either 50 or 60 Hz.

An electromagnetic field is composed of two components, the electric and the magnetic field. The electric field is created by the presence of an electric charge and is determined by the voltage. Whenever electricity is generated, transmitted or used, magnetic fields are created from the presence and motion of electric charges. The current determines the magnitude of a magnetic field. Magnetic fields are three-dimensional (described by the directional components x, y, z) and time-varying vector quantities that can be described by a number of parameters, including their frequency, phase, direction and magnitude. The strength of a magnetic field is usually designated by its magnetic flux density or B field measured in tesla (T). Magnetic field exposures from power frequency fields are in the range of μT (1×10^{-6} T).

Major sources of EMF exposure include electrical power generation, transmission and use in residential and occupational settings, and telecommunications and broadcasting. Most devices that have electrical wires are potential sources of power-frequency EMF. Although the predominant exposure is to alternating current waveforms, humans are also exposed to a mixture of frequencies, including switching events that generate abrupt spikes of high-frequency transients that can extend into radio frequencies. Residential exposures include power-frequency exposures, radio frequencies and microwave sources.

Statement of the Problem

The increased use of mobile phone in the country has resulted in the number of handsets increasing to over six million as at August 2007. There is also a corresponding increase in the number of base stations across the country.

Most of these base stations are located at areas which are very close to human settlements. A greater number of them are with the heavily populated areas of the towns and cities. Some are even located close to schools. There is therefore a growing concern and outcry from the members of the public about the possible health hazards associated with the RF radiation from the antennae installed at these base stations. There are also concerns about the handsets themselves. Most of the common complains about long duration of use of mobile phone handset include headaches, stress and general fatigue.

There are also phone users who often complain about burning sensation or heating of the ear region. The increase in temperature may be due to thermal insulation by the phone, heating of the phone resulting from its electrical power dissipation, and radio frequency (RF) exposure. Temperature changes may also be due to the interaction of the RF radiation with the biological tissue close to the location of the phone.

There has not been any independent scientific investigation to confirm some of these concerns in Ghana. There are however standard guidelines recommended by the International Commission on Non-Ionizing Radiological Commission, Federal Communication Commission of the USA and the National Radiological Protection Board of the United Kingdom. These Guidelines were based on laboratory studies, usually using animals. In Ghana however, there have been no such studies to measure the level of RF radiation and the possible biological effect. The intensity of these concerns have reach the height where there are a number of cases pending in the law courts over the installation of base stations close to residential areas in some communities.

Objectives of Research Work

The objectives of this work therefore are:

- To assess the level of intensity of Radio frequency radiation at different locations from some of the base station in Ghana.

- Measure the power densities of a number of mobile phone handset used in Ghana and calculate the specific absorption rate of the mobile phone handsets.
- Experimentally determine the temperature rise in tissue-equivalent phantoms when exposed to RF from mobile phones handsets.
- Use theoretical mathematical model to estimate temperature changes in human tissue when exposed to RF mobile phone handset.
- Estimate the level of compliance with International Commission on non-ionising Radiological Protection (ICNIRP) guidance levels and World Health Organisation recommendation on exposure levels from RF antennae compare results obtained with similar work done by other relevant internationally recognised bodies.

Relevance of Research Work

This work being a pioneering work will not only provide data on the RF base stations in Ghana but will provide baseline data for the assessment of mobile phone antenna and handsets imported into or manufacture in Ghana.

The results obtained will provide the relevant scientific data that will serve as a basis for developing appropriate regulatory guidelines for the control of non-ionising radiation from RF antennae at base station in Ghana, and for importation of cell phones.

The results of the work may help adopt appropriate radiation protection methods for both public and workers.

When the results obtained are disseminated to the public fears and concern will be addressed.

The results from this work will further go to enrich the existing scientific knowledge in this area of study.

This work consists of six chapters according to the following format: Chapter one is the introduction to thesis

Chapter two gives a historical overview of Electromagnetic radiation and also some major studies on RF base station, Specific absorption rate measurements and calculation and general information on non-ionising radiation and mobile phone antennae.

The physics of mobile telephony is discussed in chapter three. In chapter four the material and methods used to address specific objectives are described. The results obtained are presented in chapter five with discussion of results.

Chapter six deals with conclusions drawn from this work and recommendations made to policy makers and for further research work.

Scope and Limitations:

The work will cover fifty mobile phone base stations sites and fifty different models of mobile phone handsets. The choice of cell sites was based on the distribution cell sites and the density of the telephone usage. The major limitations to this work include in accessibility of some of the cell site and lack of funding for the research work.

CHAPTER TWO

LITERATURE REVIEW

History of Electromagnetic Waves

The quantitative study of electricity and magnetism began with the scientific research of the French physicist Charles Augustin Coulomb. In 1787 Coulomb proposed a law of force for charges that, like Sir Isaac Newton's law of gravitation, varied inversely as the square of the distance. Using a sensitive torsion balance, he demonstrated its validity experimentally for forces of both repulsion and attraction. Like the law of gravitation, Coulomb's law was based on the notion of "action at a distance," wherein bodies can interact instantaneously and directly with one another without the intervention of any intermediary (Nelson, 1999).

At the beginning of the nineteenth century, the electrochemical cell was invented by Alessandro Volta, professor of natural philosophy at the University of Pavia in Italy. The cell created an electromotive force, which made the production of continuous currents possible. Then in 1820 at the University of Copenhagen, Hans Christian Oersted made the momentous discovery that an electric current in a wire could deflect a magnetic needle. News of this discovery was communicated to the French Academy of Sciences two months later. The laws of force between current bearing wires were at once investigated by Andre-Marie Ampere and by Jean-Baptiste Biot and Felix Savart. Within six years the theory of steady currents was complete. These laws were also based on "action at a distance" laws, that is, expressed directly in terms of the distances between the current elements (Nelson, 1999).

Subsequently, in 1831, the British scientist Michael Faraday demonstrated the reciprocal effect, in which a moving magnet in the vicinity of a coil of wire produced an electric current. This phenomenon, together with Oersted's experiment with the magnetic needle, led Faraday to conceive the notion of a magnetic field. A field produced by a current in a wire interacted with a magnet. Also, according to his law of induction, a time varying magnetic field incident on a wire would induce a voltage, thereby creating a current. Electric forces could similarly be expressed in terms of an electric field created by the presence of a charge (Nelson, 1999).

Faraday's field concept implied that charges and currents interacted directly and locally with the electromagnetic field, which although produced by charges and currents, had an identity of its own. This view was in contrast to the concept of "action at a distance," which assumed bodies interacted directly with one another. Faraday, however, was a self-taught experimentalist and did not formulate his laws mathematically. Faraday's work did away with the idea of "action at a distance" and introduced the idea of field force.

It was left to the Scottish physicist James Clerk Maxwell to establish the mathematical theory of electromagnetism based on the experimental observation and results of Faraday. In a series of papers published between 1856 and 1865, Maxwell restated the laws of Coulomb, Ampere, and Faraday in terms of Faraday's electric and magnetic fields. Maxwell thus unified the theories of electricity and magnetism, in the same sense that two hundred years earlier Newton had unified terrestrial and celestial mechanics through his theory of universal gravitation (Yavorsky & Detlaf, 1980).

As is typical of abstract mathematical reasoning, Maxwell saw in his equations a certain symmetry that suggested the need for an additional term, involving the time rate of change of the electric field. With this generalization, Maxwell's equations also became consistent with the principle of conservation of charge (Barnes, 1965).

Furthermore, Maxwell made the profound observation that his set of equations, thus modified, predicted the existence of electromagnetic waves. Therefore, disturbances in the electromagnetic field could propagate through space. Using the values of known experimental constants obtained solely from measurements of charges and currents, Maxwell deduced that the speed of propagation was equal to speed of light. This quantity had been measured astronomically by Olaf Romer in 1676 from the eclipses of Jupiter's satellites and determined experimentally from terrestrial measurements by H.L. Fizeau in 1849. He then asserted that light itself was an electromagnetic wave, thereby unifying optics with electromagnetism as well (Nelson, 1999).

Maxwell was aided by his superior knowledge of dimensional analysis and units of measure. He was a member of the British Association committee formed in 1861 that eventually established the centimeter-gram-second (CGS) system of absolute electrical units.

Maxwell's theory was not accepted by scientists immediately, in part because it had been derived from a bewildering collection of mechanical analogies and difficult mathematical concepts. The form of Maxwell's equations as they are known today is due to the German physicist Heinrich Hertz. Hertz simplified them and eliminated unnecessary assumptions (Barnes, 1965).

Hertz's interest in Maxwell's theory was occasioned by a prize offered by the Berlin Academy of Sciences in 1879 for research on the relation between polarization in insulators and electromagnetic induction. By means of his experiments, Hertz discovered how to generate high frequency electrical oscillations. He was surprised to find that these oscillations could be detected at large distances from the apparatus. Up to that time, it had been generally assumed that electrical forces decreased rapidly with distance according to the Newtonian law. He therefore sought to test Maxwell's prediction of the existence of electromagnetic waves.

In 1888, Hertz set up standing electromagnetic waves using an oscillator and spark detector of his own design and made independent measurements of their wavelength and frequency. He found that their product was indeed the speed of light. He also verified that these waves behaved according to all the laws of reflection, refraction, and polarization that applied to visible light, thus demonstrating that they differed from light only in wavelength and frequency. "Certainly it is a fascinating idea," Hertz wrote, "that the processes in air that we have been investigating represent to us on a million-fold larger scale the same processes which go on in the neighborhood of a Fresnel mirror or between the glass plates used in exhibiting Newton's rings." (Nelson, 1999)

It was not long until the discovery of electromagnetic waves was transformed from pure physics to engineering. After learning of Hertz's experiments through a magazine article, the young Italian engineer Guglielmo Marconi constructed the first transmitter for wireless telegraphy in 1895. Within two years he used this new invention to communicate with ships at sea. Marconi's transmission system was improved by Karl F. Braun, who increased the power, and hence the range, by coupling the transmitter to the antenna through a transformer instead of having the antenna in the power circuit directly. Transmission over long distances was made possible by the reflection of radio waves by the ionosphere.

Marconi created the American Marconi Wireless Telegraphy Company in 1899, which competed directly with the transatlantic undersea cable operators.

Initially, wireless communication was synonymous with telegraphy. For communication over long distances the wavelengths were greater than 200 meters. The antennas were typically dipoles formed by long wires cut to a sub multiple of the wavelength.

Commercial radio emerged during the 1920s and 1930s. The American Marconi Company evolved into the Radio Corporation of America (RCA) with David Sarnoff as its director. Technical developments included the invention of the triode for amplification by Lee de Forest and the perfection of AM and FM receivers through the work of Edwin Howard Armstrong and others. Tom Lewis credits de Forest, Armstrong, and Sarnoff are the three visionary pioneers most responsible for the birth of the modern communications age (Nelson, 1999).

Stimulated by the invention of radar during World War II, considerable research and development in radio communication at microwave frequencies and centimeter wavelengths was conducted in the decade of the 1940s. The MIT Radiation Laboratory was a leading center for research on microwave antenna theory and design. The basic formulation of the radio transmission formula was developed by Harald T. Friis at the Bell Telephone Laboratories and published in 1946. His equation expressed the radiation from an antenna in terms of the power flow per unit area, instead of giving the field strength in volts per meter, and is the foundation of the RF link equation used by satellite communication engineers today (Nelson,1999).

Radiation

Radiation is defined as the propagation of energy through space in the form of waves or particle.

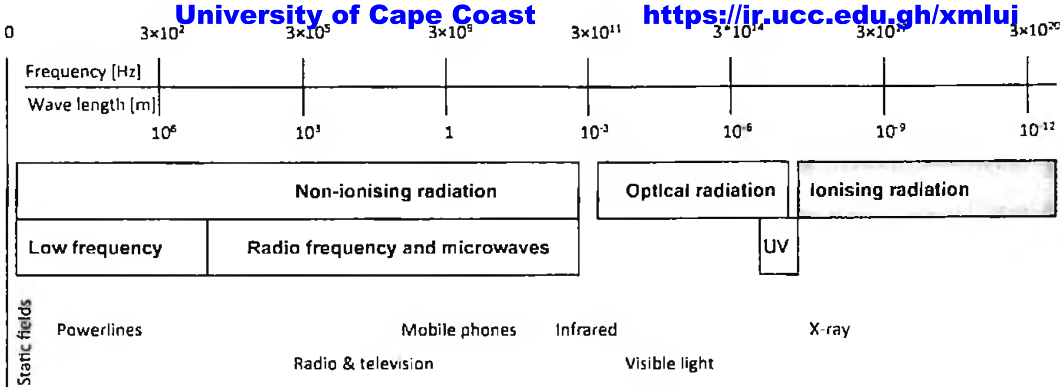

Figure 1: Electromagnetic spectrum (adapted from IARC, 2002)

Electromagnetic radiation can best be described as electric and magnetic energy moving together or radiating through space. These waves are generated by the movement of electrical charge such as in conductive metal or antenna. Electromagnetic waves travel space at the speed of light, 3.0 x 10^8m/s.

Since the speed of light in a given medium or vacuum do not change, high frequency electromagnetic waves have short wavelength and low frequency waves have long wave length.

Electromagnetic waves are carried by particles called quanta. Quanta of higher frequency (shorter wavelength) waves carry more energy than lower frequency (longer wavelength) fields.

The electromagnetic spectrum therefore include all forms of electromagnetic energy from extremely low frequency (ELF) energy, with very long wavelengths, to x-rays and gamma rays, which have very high frequencies and corresponding short wavelengths In between these are radio waves, micro waves and infra red radiation, visible light and ultra violet radiation in that order.. Electromagnetic radiation may be classified into two broad categories: Ionising radiation and Non-ionising radiation.

Ionising Radiation

Ionisation of an atom occurs when an electron is removed from a neutral atom, thereby producing a pair of ions consisting of negatively charged electron and the positively charged atom. The process of ionisation enables radiation to be detected, and also enable radiation to be shielded. This process can produces molecular changes that can lead to damage to biological tissues, including effects on the DNA, the genetic material.

Particles and electromagnetic waves which have the capacity to ionise elements in materials are referred to as ionising radiation. These are alpha particles, x-rays, beta particles and gamma radiation. Gamma radiation has the greatest penetration power and therefore interact less with materials. Beta particles are in the form of electrons and have less penetrating power. Alpha particles have the lowest penetrating power. Because of their ability to ionise particles in materials, they can cause a lot of damage to living cells and consequently results in both short term and long term effects depending on the energy of the incident radiation. Some of the possible health effects associated with exposure to ionising radiation includes radiation burns, cataract and cancer. Exposure to extremely high doses of radiation may even results in death.

In the electromagnetic spectrum, radiation with wavelengths of the order of 10^{-12}m or less are ionising and those with wavelengths greater or equal to 10^{-10}m are all non-ionising. Alpha and Beta are particulate in nature and their penetrating powers are a few centimetres in air for alpha particles to a few metres in air for beta particles.

Non-ionizing radiation

Electromagnetic fields are present everywhere in our environment but are invisible to the human eye. Electric fields are produced by the local build-up of electric charges in the atmosphere associated with thunderstorms. The earth's magnetic field causes a compass needle to orient in a North-South direction and is used by birds and fish for navigation. Apart from the natural sources of these fields there are man-made sources. This work is concerns mainly with the artificial sources.

Man-Made Sources

These are fields within a region in the electromagnetic spectrum with frequencies as low as 10Hz to as high as 300 GHz. Non – ionising radiations are generally referred to as electromagnetic fields because they have both electric and magnetic components. The photon energies of non –ionising radiation are not high enough to cause the ionisation of atoms and molecules. Non-ionising radiation energy is weak to break chemical bonds and therefore there is no similarity between biological effects of ionizing radiation and non ionising radiation. The field may be said to be time varying if the strength changes with time. The common sources of exposure to time varying electromagnetic fields are electric power lines, electrical appliances at home and work, radio and television, fields from microwave generators and radio frequency transmitters.

The frequency of the electric power in Ghana is 50 Hz but in some countries, it is 60 Hz. Amplitude Modulated (AM) radio has a frequency of around 1MHz, Frequency Modulated (FM) radio has a frequency around 100M Hz, microwave ovens have a frequency of 2450MHz and cellular (mobile) phones operate at a variety of frequencies between about 800 and 2200 MHz.

Radio frequency radiation

Radiofrequency fields are a subset of Electromagnetic Field (EMF) covering the frequency range 3 kHz to 300GHz. It is also referred to as Radiofrequency Electromagnetic Radiation (EMR) or, more often, Radiofrequency Radiation (RFR).

RFR is 'non-ionising' radiation, meaning that it is not directly able to cause molecular changes. It is considered by most scientists working in this discipline to be incapable of altering the DNA genetic material of cells.

In the last twenty or thirty years, the use of devices that emit radiofrequency radiation has increased tremendously. The most important use of RF energy is in providing telecommunication services to the public, industry and government. Radio and television broadcasting, cellular telephones, personal communications services , pagers, cordless telephones, business radio, radio communication for police and fire service, microwave point-to-point links and satellite communications are just a few of the many applications of RF energy for telecommunication. There are also non-communication uses of RF energy such as microwave ovens and radar. RF energy is also used in industrial heating and sealing where electronic devices that generate radiofrequency radiations rapidly heat the material being processed in the same way that a microwave oven cooks food. RF heaters and scalers have many uses in industry, including moulding plastic materials gluing wood products, sealing items such as shoes and pocket books and processing food products. There are also a number of medical applications of RF energy including a technique called diathermy, that take advantage of the ability of RF energy to rapidly heat tissue below the surface.

The proliferation of RF devices has been accompanied by increased concern about ensuring the safety of their use. Throughout the world many organizations, both government and nongovernmental, have established radiofrequency safety standards or guidelines for exposure. Because of different criteria, Russia and some of the Eastern European countries have more stringent safety standards than most Western countries. In Ghana there exist no such safety standards as far as radiofrequency radiations are concern.

Interaction of RF Fields with materials

The Electric and Magnetic fields interact with materials in two ways. Firstly, the electric and magnetic fields exert forces on the charged particles in the materials, thus altering the charged particles originally present.

Secondly, the altered charge particles in the materials produce additional electric and magnetic field. Materials are usually classified as being either magnetic or nonmagnetic. Magnetic materials have magnetic dipoles that are strongly affected by applied fields but non magnetic fields do not.

Nonmagnetic Materials

In nonmagnetic materials, mainly the applied E-field has an effect on the charges in the material. This occurs in three primary ways:

- Polarization of bound charges
- Orientation of permanent dipoles
- Drift of conduction charges (both electronic and ionic)

Materials primarily affected by the first two kinds are called dielectrics; materials primarily affected by the third kind are conductors.

Interaction of RF Fields with Tissue

The electric and magnetic fields produced in a body near an electromagnetic source may cause both thermal and non thermal biological effects. The effects of magnetic fields may vary with frequency and are probably greatest in biological tissue containing small amount of magnetite. Magnetite (Fe_3O_4) is a naturally occurring oxide of iron. It is a ferrimagnet but behave similarly in magnetic fields to a ferromagnet such as iron. The magnetite is found in certain bacteria and in the cells of many animals, including human beings. This is used by some species of birds and fish to provide magnetic sensitivity, which they employ in navigation. It has been calculated that the interaction resulting from the largest RF magnetic fields generated by mobile phone is extremely small (Adair, 1994) and any other effects of magnetic fields at these frequencies do not matter. It seems that generally, any biological effects from mobile phone are more likely to results from electric rather than from magnetic fields.

Thermal Effects:

Thermal effects are those caused by the rise in temperature produced by the energy absorbed from oscillating electric fields. The force produced by an electric field on charged objects, such as mobile ions present in the body causes them to move resulting in electric currents and the electrical resistance of the material in which currents are flowing results in heating. This heat input, causes the temperature to rise and it continues to do so until the heat input is balanced by the rate at which it is removed mostly by blood flowing to and from other parts of the body. This part of the body reaches their final equilibrium temperatures. In view of this slow response, the equilibrium temperature arising from the pulsed field of mobile telecommunication will essentially be determined by the average power absorbed. Among thermally vulnerable areas of the body, because of their low blood supply, are the eye and testes, and cataract formation and reduced sperm counts are well-documented acute exposure hazard (Hyland, 2000).

Heating of the Head:

Adair et al. (1999) could not measure small changes in temperature directly except that of the outer skin. Van Leeuwen et al. (1999) computed the heat deposition within the head by coupling a finite time domain model for SAR with a new thermal model.

Wainwright (2000) has applied the Pennes thermal model to SAR patterns to calculate the temperature rises generated in the brain by radiation from cellular as predicted in an earlier work (Dimbylow & Mann, 1994). The radiation source was model as a monopole antenna on a metal box and both horizontal and vertical orientations of the antenna were considered. Computations of the final steady state temperature rise were carried out for 0.25W antenna at frequencies of 900Hz and 1800Hz. The highest temperature rise found in the brain was around 0.1°C.

Non thermal effects:

The term "nonthermal" effects can have two meanings: Firstly, it could mean that an effect occurs under condition of no apparent change in temperature in the exposure animal or tissue, suggesting that physiological or exogenous mechanisms maintain the exposure object at a constant temperature. The second meaning is that somehow RFR can cause biological effects without the involvement of heat energy (or temperature independent).

Radiofrequency radiation emits low energy quanta. Between 0.9 and 1.8GHz the energy emitted is in the range 4 and 7μeV respectively. This energy is too small to break the weakest chemical bonds in genetic molecule (DNA). It is therefore impossible for RF radiation to damage DNA directly and subsequently initiate cancer. RF radiation could however produce other effects. Detectable changes can arise only if the effect of the electric field within the biological system exposed to RF fields is not marked by thermal noise. Thermal noise also known as Brownian motion is due to the thermal energy that all objects possess at temperatures above absolute zero. If the thermal energy of atoms vibrating in gases and liquids is greater than the thermal noise, a detectable biological effect could be produced. Thermal motion could lead to biological systems resonating. Non-thermal effects arises from an oscillatory similitude between the radiation and living organism which makes it possible for living organism to respond to low intensity RF fields. A good example of human vulnerability to a non-thermal, electromagnetic influence is the ability of light flashing at about 15 Hz to induce seizures in people with photosensitive epilepsy (Harding and Jeavons, 1994). In vivo evidence of non-thermal influences, including exposure to actual GSM radiation, comes predominantly from animal studies. Finally, human in vivo studies, under GSM or similar conditions, include effect on the EEG and on blood pressure. A delayed increase in spectral power density has been collaborated in the “awake” EEG of adults exposed to GSM radiation (Reiser et al., 1995). Influences on the “asleep” EEG include a shortening of the rapid-eye-movement (REM) sleep (Mann & Roschke, 1996). Exposure to mobile phone radiation also decreases the preparatory slow potentials in certain regions of the brain (Freude et al., 1998) and affects memory tasks (Krause, 2000). In 1998, Braune recorded increases in resting blood pressure during exposure to radiofrequencies.

Effects of Radiofrequency EM Radiation on Nervous System:

The effects of RF radiation on nervous system had been studied by a number of researchers. These studies involve repeated exposures with variable duration of a relatively constant amount of body tissue- part of head. In considering biological effects of RFR, the intensity and frequency of the radiation and exposure duration are important determinants of the responses. Data from some of the experiments suggest that RFR effects are cumulative over time.

Martens et al. (1995) calculated peak SAR in the head tissue to be ranging from 2-8W/kg per watt output of the device. It was found that most of the energy from a cellular telephone antenna is deposited in the shin and the outer portion of the brain (cerebral cortex). Other studies suggest that high intensity of RFR is required to alter the permeability of the blood-brain barrier. This is due to the fact that significant changes in brain or body temperature are necessary condition for the effect to occur. Chang et al. (1982) studied the penetration of B11 labelled albumin introduced into the brain of dogs. The results of the study indicate that when the head of a dog was irradiated with 1000MHz at a power density of $30mW/cm^2$, four (4) of the eleven (11) dogs studied showed a significant increase in albumin penetration compared to that of sham exposed animals.

Lin & Lin (1982) reported no significant changes in the permeability of sodium fluorescein and Evan's blue into the brain of rats with focal exposure at the head for 20min to pulsed 2450MHz RFR at 0.5-1000mW/cm^2 but increase was reported after similar exposure of the head at an SAR of 240W/kg .

When low intensity RFR was studied generally no significant effect on the blood brain-barrier was observed. For example, Gruenan et al. (1982) reported no significant change in the penetration of ^{14}C- sucrose into the brain of rats after 30minutes of exposure to pulsed or continuous wave 2800 MHz RFR of various intensities; 1-15mW/cm^2 and SAR 0-6W/kg for pulsed radiation and 10 and 40mW/cm^2 for the continuous radiation. Ward et al. (1982) studied entry of ^{3}H insulin and ^{14}C -sucrose into different areas of the brain when they irradiated rats with 2450MHz RFR for 30min at different power densities 0-30mW/cm^2 SAR 0.6 W/kg.

Cellular Morphology of the Brain:

Radiofrequency radiation – induced morphological changes of the central nervous system are shown only to occur under relatively high intensity or prolonged exposure to the radiation (Albert & De Santis, 1995), (Gordon et al.,1970) and (Tolgskaya & Gordon, 1973). However, there are several studies showing that repeated exposure at relatively low SARs caused morphological changes in the central nervous system. Gordon (1970) and Tolgskaya & Gordon (1973) reported changes in neuronal morphology in the rat brain after repeated exposure to RFR (3000 MHz) thirty-five 30 min sessions, power density of less than 10mW/cm^2 and SAR of 2W/Kg.

Another important area of research on morphological effect of RFR exposure, that could have important implication on cellular telephone use, is that on the eye. Damage to corneal endothelids, degenerative changes in cells of the iris and retina and altered visual functions were reported in non human primates after repeated exposure to RFR. Alarming, concomitant treatment with certain drugs can significantly sensitise these secular response to RFR. Effects we observed at an average SAR of 0.26 W/kg (Kues et al., 1992).

Changes in morphology, especially cell death could have an important implication on health. Injury-induced cell proliferation has been hypothesised as a cause of cancer (Preston-Martin et al., 1990).

Neural Electrophysiology

Exposure of neural tissue to RFR can conceivably cause electrophysiological changes in the nervous system. Changes in neuronal electrophysiology, evoked potentials and EEG have been reported. Again, the possible involvement of RFR-indirect tissue healing cannot be ruled out to some of the experiments. However, some effects were observed at low intensities and after repeated exposure suggesting cumulative effect. Chou & Guy (1978) exposed temperature controlled samples of isolated frog sciatic nerves, cat saphenus nerves and rabbit vague were to 2450 MHz RFR. They reported no significant change in the characteristics of the compound action potentials in their samples during exposure to either continuous waves with SAR between 0.3 – 1500 W/kg or pulsed with peak SAR between 0.3 – 220 W/kg radiation. Therefore, no direct field stimulation of neural activity was observed.

Several studies investigated the effect of RFR on evoked potential in the brain. Johnson and Guy recorded evoked potentials in the thalamus of cats in response to stimulation of the contra lateral forepaw during exposure to continuous the 918 MHz RFR for 15 min at power densities of 1-40 mW/cm^2 at the head. A power density dependent decrease in latency of some of the late components respoanses of the thalamic revoked potential was observed. These data were interpreted as that RFR affected the multisynetic neural pathway, which relates neural information from the skin to the thalamus. Interestingly, warming the body of the animals decreased the latency of both the initial and late components of the evoked potential. Taylor and Ashleman recorded spinal cord ventral roots responses to electrical stimulation of the ipsilateral gastrochemius nerves in cats. The spinal cord was inactivated with continuous wave of 2450 MH_Z RFR at an incident power of 7.5W. Decreases in latency and amplitude of the reflex response were observed during 3 min exposure and responses returned to normal immediately after exposure. They also reported that raising the temperature of the spinal cord produced electrophysiological effects similar to those of RFR.

In a chronic exposure experiment, Chou et al exposed rabbit to continuous wave of 2545 MH_Z RFR at 1.5 mW/cm^2 (2 hours/day 5 days/week for 90 days). Electroencephalograph and evoked potentials were measured at the sensory-motor and occipital cortex at various times during the exposure period. The researchers reported large variations at the data and a tendency towards a decreased response amplitude in the latter part of the experiment, which is after a longer period of repeated exposure.

Changes in Neurotransmitter Functions

Neurotransmitters are molecules that transmit information from one nerve cell to another. There are different types of neurotransmitters in the brain. Early studies have reported changes in various neurotransmitters (catecholamines, sarotonin and acetylcholine) in the brain of animal only after exposure to high intensities of RFR (Catravas et al. 1976; Marritt et al., 1976; Modak, 1987 & Snyder, 1971).

However, there are more recent studies that show changes in neurotransmitter functions after exposure to low intensities of RFR. Furthermore, studies indicate a dynamic response of the nervous system to RFR depending on the duration and number of exposure, and interaction of these two parameters. In addition, different brain region could respond different to RFR.

Parameters of exposure are important determinants of the outcome of biological effect of RFR. Particularly, different durations of acute exposure could lead to different biological effect and, consequently, the effects of repeated exposure depend upon the duration of each exposure session (Dutta et al. 1992; Lai et al.1987; Lai et al. 1988).

Metabolic Changes in Neural Tissues

Metabolic changes in brain tissues have been reported after RFR exposure. Gandhi & Ross (1989) reported that exposure of rat cerebral cortex synaptosome to 2800 MH_Z RFR at power densities greater than $10mW/cm^2$ and SAR, 1mW/gm per mW/cm^2 increased by 32π incorporation into phosphoinositides. These phospholipids play an important role in membrane functions and act as second messengers in the transmission of neural information between neurons.

Several studies investigated the effects of RFR exposure on energy metabolism in the rat brain. Surprisingly, changes were reported after exposure to relatively low intensity RFR for a short duration of time (minutes). The effects depend on the frequency and modulation characteristics of the RFR and did not seem to be related temperature changes in the tissue. Sanders (1980, 1984) and associates studied the component of the mitochondria electron transport system that generates high-energy molecules for cellular functions. The compounds nicotinacide adenosine dinucleotide (NAD), adenosine triphosphate (ATP) and creative phosphate (CP) were measured in the cerebral cortex of rats exposed to RFR. A decrease in concentration of ATP and CP and an increase in NAD were observed in the cerebral cortex.

Cytogenetic Effects

Cytogenetic effects have been reported in various types of cells after exposure to RFR. Recently, several studies have reported cytogenetic changes in brain cells by RFR and these results could have important indication on the health effects of RFR. Singh et al. (1994) reported significant decreases in poly-ADP-ribosylation, a process involved in chromatin functions in the brain of rat after sixty days of exposure to a power density of $1mW/cm^2$ at 2450 MHz. Sarkar et al. (1994) reported changes in DNA sequences in mouse brain cells after exposure to RFR of $1mW/cm^2$ at 2hr/day for 120, 150 and 200 days respectively. Lai & Sigh (1995) reported an increase in single strand DNA breaks in brain cells of rats after 2 hours of exposure to 2450MHz RFR (whole body SAR 0.6 and 1.2 W/kg). Genetic damages to glial cells can result in carcinogenesis. However, since neurons do not undergo mitosis, a more likely consequence of neuronal genetic damage is changes in functions and cell death, which could either lead to or accelerate the development of neurodegenerative diseases. There have been reports of an increase in DNA double strand break in brain cells of rats after acute exposure to RFR (Lai & Singh, 1996). Double strand breaks, if not probably repaired is known to lead to cell death.

Interestingly, RFR-induced increases in single and double strand DNA breaks can be blocked by treating the rats with melatonin (Lai & Singh, 1997). Since these compounds are potent free radical scavengers, this work suggest that free radicals may play a role in the genetic effect of RFR. If free radicals are involved in the RFR-induced DNA strand breaks in brain cells then results from this study could have an important implication on the health effect of RFR exposure. Involvement of free radical in human diseases, such as cancer and arteriosclerosis, has been suggested. Free radicals also play an important role in aging processes, which have been ascribed to be a consequence of accumulated oxidative damage to body tissue (Forster, 1996; Schal, 1991), and involvement of free radicals in neurodegenerative diseases, such as Alzheimer's, Huntington and Parkinson has also been suggested (Borlongan, 1996; Owen, 1996). Furthermore, the effects of free radicals could depend on the nutritional status of an individual for example, availability of dietary antioxidants (Arnoma, 1994), consumption of alcohol (Kurose, 1996) and amount of food consumption (Wachsman, 1996). Various life conditions such as psychological stress (Hague, 1994) and strenuous physical exercise (Clarkson, 1995) have been shown to increase oxidative stress and enhance the effects of free radicals in the body. Thus, one can also speculate that some individuals may be more susceptible to the effects of RFR exposure.

Calcium Efflux

Calcium plays an important role in many biological processes, especially in the function of nerve cells. The exposure of pieces of chick brain to undulated RF fields caused a small increase in the release of radio labelled calcium ions (calcium efflux) (Bawin et al., 1975). The effect occurred at relatively low power, it was thought not to be heating. It remains the most examples of nonthermal effects RFR. This observation was confirmed by Blackman et al. (1979, 1980) who used a number of different frequencies of amplitude modulation (3-30M_Z) and found that the effect was maximal at 16H_Z. This led to the view that modulation as or near 16H_Z might be critically important and a number of other studies using this frequency of amplitude modulation have also reported increases in the diffusion of calcium out of isolated fragments of nerve cells and cultured human neuroblastoma cells. Such calcium efflux may partly reflect movement of calcium out of neurons. Kittel et al. (1996) using electron microscopy to identify labelled calcium in a particular part of the brain (the medial habenular nucleus), found that exposure of mice in vivo to 2.45 GHz RF fields, amplitude modulated at 16 Hz, caused a reduction in the number of calcium containing vesicles inside nerves cells and an increase in the amount of calcium precipitated on the surface of the cells. However, calcium efflux from brain experts almost certainly involve a number of other factors, including the release of calcium bound or adherent to membranes and simply trapped in the interstices of the tissues. It is also likely to be influenced by temperature.

Adey (1989, 1993) has suggested that changes in calcium efflux may be due to an amplification process in which weak electric field might be set up to the tissue at the extremely low frequency of amplitude modulation and that these might act as a trigger for the initiation of long range cooperative events within the cell membrane. The group thought that, in the twinge aerial, such calcium exchange might be associated with the small fluctuating in the potential across nerve cell membranes, of the type that can be detected with gross recording electrodes placed on the brain or even in the scalp.

From the foregoing discussions, it is clear that biological effects of RFR are caused by the complex interactions of different exposure parameters. However, knowledge of possible health effects of RFR is still inadequate and inconclusive. The biological and health consequences of these exposure conditions need further understanding.

The Risk of Childhood Leukaemia

Until very recently, childhood leukaemia risk in relation to RF electromagnetic fields has only been studied with an ecological study design; that is, studies investigating leukaemia incidence rates indifferent vicinities to broadcast transmitters, but no information on the individual's exposure is available Ahlbom et al., (2002).This type of study is difficult to interpret and usually only considered as hypothesis-generating. Some of the ecological studies included very small numbers of subjects and it is likely that they would not have been published had they been negative, which raises concerns about publication bias. Some studies were only initiated because there was already a suspicion of a cancer cluster. Three somewhat larger incidence studies are noteworthy. Hocking et al. (1996) compared the childhood leukaemia incidence rate in three municipalities of Sydney surrounding a triangle of television towers with the respective rate of six outer municipalities and observed a statistically significantly increased rate ratio of 1.6. A re-analysis including further outer municipalities later confirmed the association, although somewhat weaker, but more importantly pointed out that the increase was not compatible with a dose–response concept, as the increase was restricted to one of the three inner municipalities and was most apparent before the towers started 24 h broadcasting (McKenzie et al.,1998). Dolk et al. (1997) had a large study base investigating cancer risk in the vicinity of 21 high-power television and radio transmitters in the UK; in the 2 km circle, they observed hardly any more childhood leukaemia cases than expected, namely 10 versus 8.9, yielding a risk estimate of 1.1. Michelozzi et al. (2002) studied the leukaemia incidence in the vicinity of the broadcast transmitters of Radio Vatican, Rome, Italy, and observed a marked increase in childhood leukaemia incidence rates with decreasing distance to the towers. While RF electromagnetic field exposure was indeed assumed to be relevant, due to the fact the more than 30 antennas with output powers between 5 and 600 kW were installed in the area, the analysis was based on only eight cases within the 10 km circle and the relative risk estimate for the closest circle of 0–2 km was based on one observed case versus 0.2 expected, yielding a statistically non-significantly elevated estimate of 6.1. Overall, these studies preclude firm conclusions, but the ambiguous findings together with the concerns about childhood leukaemia associated with ELF magnetic fields merited more systematic studies with improved exposure assessment on this topic.

The first case–control study was completed in South Korea (Ha et al., 2007), with a correction of the main results table in a reply to a letterin (Schu et al. 2008). The study involved 1928 childhood leukaemia cases diagnosed between 1993 and 1999 and1:1 matched hospital-based controls referred to the same hospitals as the cases but due to respiratory illnesses. RF electromagnetic field exposure was calculated using a field prediction programme and also the distance to one of 31 included amplitude-modulated (AM) radio transmitters was estimated. Although there was an excess of leukaemias in the 2 km circles of the transmitters (a relative risk estimate of 2.15, 95% CI 1.00–4.67), no association was seen between childhood leukaemia risk and the predicted field strengths (0.83, 95% CI 0.63–1.08 for the highest quartile of exposure); in the intermediate categories, relative risks were often statistically significantly decreased. For peak exposure, which is the highest value among those estimated for the 31transmitters, no overall association was seen, but the relative risk estimates in the highest exposure category were increased for lymphocytic leukaemia and decreased for myelocytic leukaemia.

The second case–control study was conducted in German municipalities surrounding 16 AM radio and 8 frequency-modulated (FM) radio and television broadcast transmitters, Merzenich et al. (2008). Exposure assessment for 1959 childhood leukaemia cases and three matched population-based controls was performed using field prediction programmes Schmiedel (2008). Considering total RF electromagnetic field exposure, the relative risk estimate was 0.86 (95% CI 0.67–

1.11), comparing the upper (_95%/0.701 V m21) and lower (,90%/0.504 V m21) quartile of the field distribution. An analysis for AM and FM broadcast transmitters separately did not show increased risks for leukaemia. No increased risk was seen for the first exposure decade alone, which was the time period without noticeable dilution from mobile telecommunication networks. The relative risk estimate was 1.04 (95% CI 0.65–1.67) among children living within 2 km to the nearest broadcast transmitter compared with those living in a distance of10–15 km. Together these two large-scale studies show no evidence for an association between RF electromagnetic fields and childhood leukaemia risk.

Problems arising from review

Elucidation of the biological effects of RF exposure requires a careful review and critical analysis of the available literature. Such review requires differentiation of established effects and mechanism from speculative and unsubstantiated reports. Although there is considerable agreement among scientists concerning the biological effects and potential hazards of RF fields, there are areas of disagreements. Another thorny issue is the definition of what constitute hazard. One objective definition of injury is irreversible change in biological functions as observed at the organ or system level. With this definition it is possible to define a hazard as a probability of injury on statistical basis. It is important to differentiate between the hazard levels at which injury may be sustained and effect or perception. All effects are not necessarily hazards.

Another problem is that a critical review of studies into the biological effects of RF fields indicates the many of the investigations suffer from inadequacies of either technical facilities and energy measurement skills or insufficient control of the biological specimens and the criteria for biological change. More sophisticated conceptual approaches and more rigorous experimental design must be developed.

In this work, a rigorous technique was used to investigate the thermal effects of the RF fields from typical mobile phone handsets.

CHAPTER THREE

ANTENNAS AND PHYSICS OF MOBILE TELEPHONY

Types of Antennae

In this section we consider types of commonly used antennae. Most antennae consist of a juxtaposition of conductor and insulator, which may be dielectric or may be air or free space. Any structure which will support a current on its surface, or guide or modify the direction of propagation of an electromagnetic wave, may be pressed into service as a kind of antenna.

- Wire antennas. The wire need not be straight.
- Loop antennas. The loop need not be circular. There can be more than one turn.
- Mobile phone mast
- Aperture antennae. Examples are waveguide horns.
- Slot antennae. These are holes in waveguide or cavities.
- Reflector antennas. These are used in combination with a "feed" formed from one of the other types.
- Helix antennas. These are used to generate circular polarisation.
- Dielectric rod antennas. A dielectric extension to the waveguide. Dielectrics are material structures containing bound electrons. Under the influence of an incident electromagnetic field, the electrons can move, accelerate, and therefore re-radiate. Thus, the presence of dielectrics close to an antenna conductor structure can profoundly modify the performance of the antenna.

A dielectric lens may be used in front of a horn feed in a similar manner to a physical optical glass lens; but its action is then to modify the wave velocity, and therefore the curvature of the wavefront across the antenna.

- Microstrip or patch antennas. These are becoming increasingly popular for microwave applications as they are small and easily fabricated. An area (almost any shape is possible) of conductor is excited on the surface of a dielectric substrate having a backplane conductor. The excitation can be by means of microstrip transmission line, from either the front, or from the back through an aperture in the backplane. It can also be by means of front illumination from a horn feed; the patches are of different sizes and can mimic the phase profile of a parabolic reflector dish even though they are deposited on a flat plane surface. Microstrip antennas have substrate dielectric constant in the range 3 upwards. This means that there is more energy stored in the reactive near field region, so the antennas are narrow band high Q devices compared to other types of antenna. This is not so much of a problem at the higher microwave frequencies, where narrow fractional bandwidth still gives useful signal handling capacity.
- Array antennas. These are formed from multiples of the other kinds of antennas. Active arrays have each element individually driven by its own feed, whereas passive arrays have a primary radiator passing near-field energy to parasitic elements.
- Yagi Uda antenna ("Yagis"). These are passive arrays, with a single driven element, and the other elements driven parasitically. The elements are strung out along the direction of propagation. The phase of the currents in each passive element is such that when the phase delay is added for the wave to get

from one element to the next, the individual currents all contribute to the radiated field which are in phase with each other at the front of the antenna. A rule of thumb for Yagis is that the bore sight gain (as a field strength factor, not in decibels) is equal to the number of elements (including the driven dipole and any reflector) minus 0.5. For example, a three element Yagi has gain about 2.5; a six element Yagi has gain about 5.5, and a ten element Yagi has gain about 9.5. Here, we assume the design is near-optimum. This gives us a half-power-beamwidth for a 10 element Yagi of roughly 30 degrees. To steer a 10 element Yagi off its target, we would have to swing it through about 15 degrees. Thus even quite large Yagis are not as directional as one might think. The 10 element Yagi has effective area (by the formula above) 0.76 λ^2 so it intercepts radiation over an area equivalent to a disk of radius about 0.5λ, which is about twice the physical transverse extent of its elements.

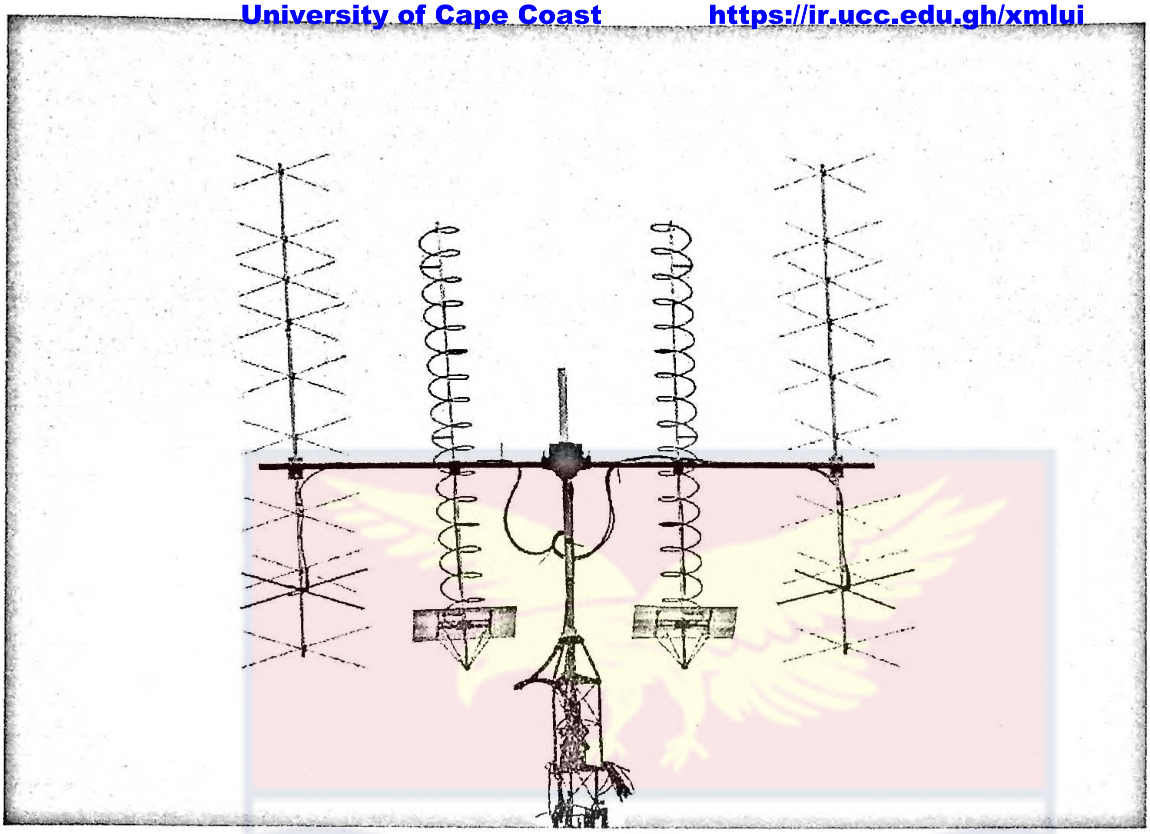

Plate 1: Crossed Yagi antennas for circular polarisation

- Log-periodic antennas. These are wideband antennas consisting of dipoles of successively diminishing length connected in parallel across the feed. Only that dipole which is close to a half wavelength long loads the feed; the dipoles behind and in front act as reflector and director to give the array a little gain.

Plate 2: An Example of Log-Periodic Antenna

- Transmission line antennas. These are leaky transmission lines whose wave velocities are close to that of waves in free space. The resulting "phase matching" condition allows resonant transfer from the transmission line to the free space wave. They can also be used in wideband applications if the transmission line is reasonably non-dispersive.
- Active antennas. The individual transmitter modules form part of the radiating structure. This method is proposed for arrays.

- Phased array antennas. By altering the phase shift between successive elements in an array antenna, the bore sight direction may be steered electronically without physically moving the antenna structure.

Aperture antennas

Aperture antennas include those used for such applications as satellite-earth stations, point-to-point microwave radio and various types of radar applications. Generally, these types of antennas have parabolic surfaces and many have cross sections. They are characterized by their high gain which in transmission of power is a well defined collimated beam with little angular divergence. Systems using aperture antennas operate at microwave frequencies, i.e., generally above 900MHz.

Those systems involved in telecommunications operate with power levels that depend on the distance between transmit and receive antennas, the number of channels required (bandwidth) and antenna gains of transmit and receive antennas. The antennas used typically have cross sections, where antenna diameter is an important characteristic that determines the antenna gain. With regards to some operations, such satellite-earth station transmitting antennas, the combination of high transmitter power and large antenna diameter (high gain) produces regions of significant power density that may extend over relatively large distances in the main beam. Many ''dish'' type antennas used for satellite-earth station transmission utilize the Cassegrain design in which power is fed to the antenna from a waveguide located at the center of the parabolic reflector. Radiation from this source is then incident on a small hyperbolic sub-reflector located between the power feed and the focal point of the antenna and is then reflected back o the main reflector resulting in the transmission of a collimated beam. An example of this is illustrated in figure 2.

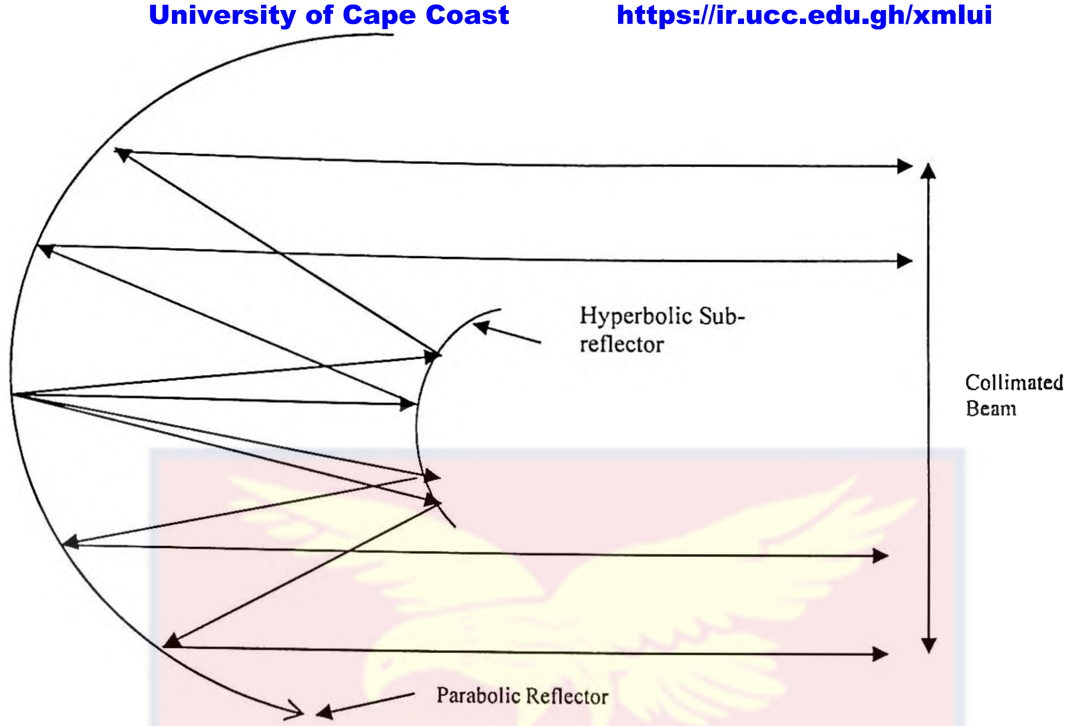

Figure 2: Schematic diagram of Cassegrain Antenna

Because of the highly directional nature of these and other aperture antennas, the likelihood of significant human exposure to RF radiation is considerably reduced. The power densities existing at locations where people may be typically exposed are substantially less than on-axis power densities. Factors that must be taken into account in assessing the potential for exposure are main-beam orientation, antenna height above ground, location relative to where people live or work and the operational procedures followed at the facility.

Satellite-earth uplink stations have been analyzed and their emissions measured to determine methods to estimate potential environmental exposure levels. An empirical model has been developed, based on antenna theory and measurements, to evaluate potential environmental exposure from these systems (Hyland, 2000). In general, for parabolic aperture antennas with circular cross sections, the following information and equations from this model can be used in evaluating a specific system for potential environmental exposure (Lewis & Newell, 1985).

Antenna Surface

The maximum power density directly in front of an antenna (e.g., at the antenna surface) can be approximated by the following equation:

$$S_{surface} = \frac{4P}{A} \quad (1)$$

Where $S_{surface}$ = maximum power density at the antenna surface

P = power fed to the antenna

A = physical area of the aperture antenna

Near Field and Far-Field zones

Sources of RF electromagnetic fields may have widely different characteristics. For the purposes of evaluation of human exposure and protection against harmful exposures, RF sources can be divided as small antennas, that is, antennas whose dimensions are less than the wavelength and large antennas whose dimensions are greater than the wavelength. The space around a source antenna is often divided into two zones-the near field zone and the far field zone. The near field zone can also be further divided into two regions, namely, the reactive near-field region and the radiating near-field region.

Near-Field Region

In the near-field, or Fresnel region, of the main beam, the power density can reach a maximum before it begins to decrease with distance. The extent of the near-field can be described by the following equation (D and λ in the same units):

$$R_{nf} = \frac{D^2}{4\lambda} \qquad (2)$$

where R_{nf} = extent of near-field

D = maximum dimension of antenna (diameter if circular)

λ = wavelength

The magnitude of the on-axis (main beam) power density varies according to location in the near-field. However, the maximum value of the near-field, on-axis, and power density can be expressed by the following equation:

$$S_{nf} = \frac{16\eta P}{\pi D^2} \qquad (3)$$

where: S_{nf}= maximum near-field power density

η= aperture efficiency, typically 0.5-0.75

P= power to antenna

D= antenna diameter

Aperture efficiency can be estimated, or a reasonable approximation for circular apertures can be obtained from the ratio of the effective aperture area to the physical area as follows:

$$\eta = \frac{\left(\frac{G\lambda^2}{4\pi}\right)}{\left(\frac{\pi D^2}{4}\right)} \qquad (4)$$

Where η = efficiency for circular aperture

G = power gain in the direction of interest relative to an isotropic radiator

λ = wavelength

D = antenna diameter

If the antenna gain is not known, it can be calculated from the following equation using the actual or estimated value for aperture efficiency:

$$G = \frac{4\pi\eta A}{\lambda^2} \qquad (5)$$

η= aperture efficiency

G= power gain in the direction relative to an isotropic radiator

λ= wavelength

A= physical area of the antenna

Transition Region

Power density in the transition region decreases inversely with distance from the antenna, while power density in the far-field (Fraunhofer region) of the antenna decreases inversely with the square of the distance. For purposes of evaluating RF exposure, the distance to the beginning of the far-field region (farthest extent of the transition region) can be approximated by the following equation:

$$R_{ff} = \frac{0.6D^2}{\lambda} \qquad (6)$$

Where R_{ff} = distance to beginning of far-field

D = antenna diameter

λ= wavelength

The transition region will then be the region extending from R_{nf} , calculated from Equation 6, to R_{ff}. if the location of interest falls within this transition region, the on-axis power density can be determined from the following equation:

$$S_t = \frac{S_{nf} R_{nf}}{R} \quad (7)$$

where: S_t= power density in the transition region

S_{nf}= maximum power density for near-field

R_{nf} = extent of near-field

R = distance to point of interest

Far-Field Region

The power density in the far-field or Fraunhofer region of the antenna pattern decreases inversely as the square of the distance. The power density in the far-field region of the radiation pattern can be estimated by the general equation discussed earlier:

$$S_{ff} = \frac{PG}{4\pi R^2} \quad (8)$$

Where: S_{ff} =power density (on axis)

P = power fed to the antenna

G = power gain of the antenna in the direction of interest relative to an isotropic radiator

R = distance to the point of interest

In the far-field region, power is distributed in a series of maxima and minima as a function of the off-axis angle (defined by the antenna axis, the center of the antenna and the specific point of interest). For constant phase, or uniform illumination over the aperture, the main beam will be the location of the greatest of these maxima. The on-axis power densities calculated from the above formulas represent the maximum exposure levels that the system can produce. Off-axis power densities will be considerably less.

For off-axis calculations in the near-field and in the transition region it can be assumed that, if the point of interest is at least one antenna diameter removed from the center of the main beam, power density at that point would be at least a factor of 100(20dB) less than that value calculated for the equivalent distance in the main beam (Hankin, 1986).

For practical estimation of RF fields in the off-axis vicinity of aperture antennas, use of the antenna radiation pattern envelope can be useful. For example, for the case of an earth station in the fixed-satellite service, the Federal Communication Commission's rules specify maximum allowable gain for antenna side lobes not within the plane of the geostationary satellite orbit, such as at ground level (FCC, 1997). In such cases, the rules require that the gain of the antenna shall lie below the envelope defined by:

$$32-\{25\log_{10}(\theta)\}dB \text{ for } 1^{\circ} \leq \theta \leq 48^{\circ};$$

and -10dBi for $48^{\circ} < \theta < 180^{\circ}$

where θ = the angle in degrees from the axis of the main lobe

dBi= dB relative to an isotropic radiator

The use of the gain obtained from these relationships in simple far-field calculations, such as Equation 8, will generally be sufficient for estimating RF field levels in the surrounding environment, since the apparent aperture of the antenna is typically very small compared to its frontal area.

The simplest kind of aperture antenna consists of a tapered waveguide transition in the form of a "pyramidal horn"

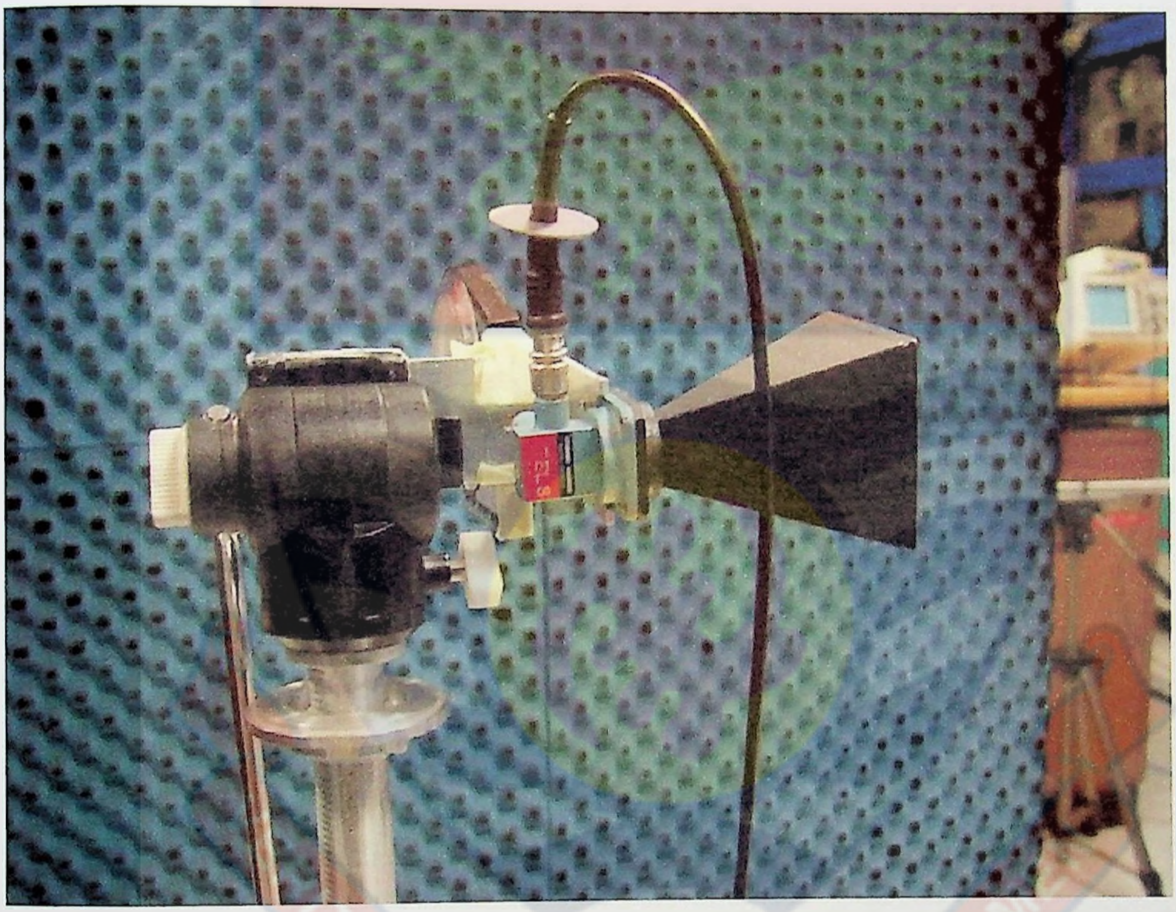

Plate 3: A pyramidal horn antenna on swivel mount

The TE_{10} mode in a rectangular waveguide has longitudinal components of magnetic field. As the waveguide is flared to form the horn pyramid, the longitudinal magnetic field components become less and the characteristic impedance of the TE mode approaches that of free space, 377 ohms.

This kind of pyramidal horn aperture antenna is very important in the laboratory, as it is one of the few types of antenna whose bore sight gain may be very accurately calculated. Consequently, it is used for producing reference field strengths and for calibrating the gains of other antennas.

A variant on the rectangular pyramidal horn is the circular horn feed. Such an aperture antenna is commonly used with a circularly symmetric waveguide mode to produce uniform illumination of a Cassegrain antenna, which has a circular reflector dish of much larger diameter than the feed. The large reflector dish produces higher gain. The circular waveguide feed can also be used to produce circular polarisation.

Most ground based small broadcast satellite receiver dishes have a small horn feed of low gain placed at the focus of a dish between 0.5 and 1 metre diameter. Often the feed is offset from the bore sight direction of the reflector dish; this "offset feed" arrangement directs the main beam away from the feed, and this result in less blockage and improved side lobe performance.

If the main beam in a Cassegrain antenna hits the feed, or the sub-reflector, it will be diffracted around the obstacles and radiation will be scattered or diffracted into the side lobe directions. The effective area of the dish is reduced, and the interference with other satellite systems from the side lobes will be increased. This is not so important in deep space antennas. If we look at the Tidbinbilla deep space tracking antenna, we see there are two reflectors between the main feeds and the main beam. The sub-reflector at the focus of the large 75 metre dish is convex. The feeds are pointing along bore sight, and are arranged to have a bean divergence angle which is just sufficient to completely illuminate the sub-reflector. The sub-reflector returns the energy to the main reflector, and again the reflections are arranged so that there is minimal spill over at the edges of the dish, although maintaining uniform illumination as far as is possible.

The feeds are also conveniently located at the centre of the main dish, which moves little as the dish is steered. This has mechanical advantages, and makes the final HPA and LNA electronics more accessible for servicing.

Aperture antennas such as this are used in "very long baseline interferometry" methods. Here, two or more high gain large antennas, having large collecting areas, are separated by many hundreds of kilometres, and used to synthesize an aperture array having the diameter of the baseline separation of the dishes. Radio astronomers use these systems to pinpoint the location of radio sources to great accuracy in elevation and azimuth.

Mobile Telephony

Mobile telephony is based on two way communication between a portable handset and the nearest base station. Every base station serves as a cell varying from hundreds of metres in extent in densely populated areas to kilometres in rural areas, and is connected to both the conventional land line telephone network and, by tightly focussed line-of-sight microwave links, to neighbouring stations. As the user of a mobile phone moves from cell to cell, the cell is transferred between base-stations without interruptions. The radio communication utilizes microwaves at 900 MHz or 1800 MHz to carry voice information via small modulations of the wave's frequency. A base-station antenna typically radiates 60 W and a hand set between 1 and 2 W. The antenna of a handset radiates equally in all directions but a base-station produces a beam that is much more directional. In addition, the stations have subsidiary beams called the side-lobes, into which small fraction of the emitted power is channelled. Unlike the main beam, these side-lobes are localized in the immediate vicinity of the mast, and, despite their low power, the power density can be comparable with that of the main beam much further away from the mast.

A handset that is in operation also has a low frequency magnetic field associated with it, not with the emitted microwaves, but with surges of electric current from the battery that are necessary to implement "time division multiple access" (TDMA). This system is currently used to increase the number of people who simultaneously communicate with a base station. Every communication channel has eight time slots, therefore the average power of a handset is one-eighth of the peak values cited above-i.e, is between 0.125 W and 0.25 W, which is transmitted as 576μs burst. Together, the eight slots define a frame, the repetition rate of which is 217 Hz. Transmission by both handsets and base-stations are grouped into multi-frames of 25 by the absence of every 26th frame. This results in additional low-frequency pulsing of signal at 8.34 Hz, which unlike permanent feature of the emission. With handset that have an energy-saving discontinuous transmission mode (DTX), there is an even lower frequency pulsing at 2Hz, which occurs when the user is listening

The close proximity of a mobile telephone antenna to the user's head leads to the deposition of relatively large amount of radiofrequency energy in the head. The relatively fixed position of antenna to the head causes a repeated irradiation of a more or less fixed amount of body tissue. Exposure to RFR from mobile telephones is of a short-term, repeated nature at a relatively high intensity, whereas exposure to RFR emitted from cell masts is long duration but a very low intensity. The biological and health consequences of these exposure conditions need further understanding.

Radio frequency Dosimetry

The Dosimetric quantities of the RF radiation are the power density and the specific absorption rate (SAR). In this section attempt have been made to discuss these two quantities and how they translate into biological effects.

Power density

This is the rate of flow of electromagnetic energy per unit surface area usually expressed in Watts per square metre. The following formula enables the calculation of power density to be made and assumes a field impedance of 377 ohm:

$$P_d = \frac{E^2}{377} \qquad (9)$$

where E is electric field in volt per metre.

Model for Predicting Power Density

Prediction of power density in the far field of the antenna is given by

$$S = \frac{PG}{4\pi R^2} \qquad (10)$$

Where S = power density (in exp mW/cm^2)

P= power input to the antenna (mW)

G is power gain of the antenna in the direction of interest relative to an isotropy radiator,

R is distance to the centre of radiation of the antenna

The expression for S can be written as

$$S = \frac{EIRP}{4\pi R^2} \qquad (11)$$

Where EIRP = equivalent (or effective) isotropic radiated power.

Power gain G is expressed in log to base ten, that is decibel, dB a conversion required using the relation:

$$G = 10^{\frac{dB}{10}} \quad (12)$$

where the operating power is expressed in terms of "effective radiation power or 'ERP' instead of EIRP. ERP is power referenced to a half wave dipole radiator instead of to an isotropic radiator.

To convert ERP unto EIRP we multiply the ERP by the factor 1.64 which is the gain of a half wave dipole relative to an isotropic radiator.

$$S = \frac{EIRP}{4\pi R^2} = \frac{1.64\ ERP}{4\pi R^2} = \frac{0.41\ ERP}{\pi R^2} \quad (13)$$

For a truly worst case prediction of power density at or near surface such as at ground level or on a roof top, 100% reflection of incoming radiation can be assumed, resulting in potential doubling of predicted field strength and four– fold increase in (for field equivalent) power density. In that case Equations (9) and (10) could be modified to obtain:

$$S = \frac{(2)^2\ PG}{4\pi R^2} = \frac{PG}{\pi R^2} = \frac{EIRP}{\pi R^2} \quad (14)$$

In order to predict ground level field strength and power density a more realistic approximation for ground reflection we assume 1.6 fold increases in field strength leading to increase power density of 2.56 (1.6 x1.6). When equation (10) is modified the expression below is obtained.

$$S = \frac{2.56\ EIRP}{4\pi R^2} = \frac{0.64\ EIRP}{\pi R^2} \quad (15)$$

If ERP is used in Equation (15) the relation because

$$S = \frac{0.64\ EIRP}{\pi R^2} \frac{(0.64)(1.64)\ ERP}{\pi R^2} \qquad (16)$$

$$= \frac{1.05\ ERP}{\pi R^2} \qquad (17)$$

It is convenient to use the microwatt per centimetre squared unit (μw/cm^2) instead of mW/cm^2 in describing power density.

Equation (17) can be reduced further in the form

$$S = \frac{33.4 ERP}{R^2} \qquad (18)$$

Relative Gain and Main Beam Calculation

The equations above can be used to calculate fields for a variety of radiating antennas such as omni-directional radiations, dipole antennas and antennas incorporating directional arrays. Information concerning an antenna's vertical radiation pattern known as the relative field factor (relative gain) can be incorporated into the calculations to arrived at a more accurate representation of the field at the point of interest.

The modified equation for accurate calculation of the power density on the ground is gain by:

$$S = \frac{33.4\ (F^2)\ ERP}{R^2} \qquad (19)$$

where S is power density in μw/cm^2 ; F is relative field factor (relative numeric gain); ERP is power density in watts and R is distance in meters from the antenna

Specific Absorption Rate

The RF dose rate is characterised by the specific absorption rate, which is used to normalise the rate of RF energy input into biological systems.

In dosimetry, the transfer of energy from electric and magnetic fields to charged particles in an absorber is described in terms of the specific absorption rate (SAR). "Specific" refers to the normalization to mass; "absorption," the absorption of energy; and "rate," the time rate of change of the energy absorption. SAR is defined, at a point in the absorber, as the time rate of change of energy, $\left(\frac{\partial \omega_c}{\partial t}\right)$ transferred to charged particles in an infinitesimal volume at that point, divided by the mass of the infinitesimal volume.

$$SAR = \{\partial W_c / \partial t\} / \rho_m \qquad (20)$$

where ρ_m is the mass density of the object at that point. For sinusoidal fields, the time-average SAR at a point is given by the term $<P_c> / \rho_m$. This is also called the *local SAR* or *SAR distribution* to distinguish it from the *whole-body average SAR*. The average SAR is defined as the time rate of change of the total energy transferred to the absorber, divided by the total mass of the body. From Poynting's theorem, for the time-average sinusoidal steady-state case, the whole body average SAR is given by

$$Average\,SAR = \int_V < P_c > dV / M \qquad (21)$$

where M is the total mass of the absorber. In practice, the term "whole-body average SAR" is often shortened to just "average SAR." .The units of SAR are watts per kilogram.

The local SAR is related to the internal **E**-field by the expression

$$SAR = P / \rho_m = \sigma |E|^2 / \rho_m = \omega \varepsilon_o \varepsilon_r |E|^2 / \rho_m \qquad (22)$$

Where σ is the conductivity of the material of the body, ρ_m is the mass density,ω is the frequency in radians of the applied field, ε_o is the permittivity of free space and ε_r is the relative permittivity of material. Thus, if the **E**-field and the conductivity are known at a point inside the object, the SAR at that point can easily be found; conversely, if the SAR and conductivity at a point in the object are known, the **E**-field at that point can easily be found. P is the absorbed-power density (Durney and Massoudi et al. 1986). In this study measurements were done inside a tissue equivalent phantom.

Absorption Characteristics of Radio Frequency Radiation

Poynting's Theorem

This is a statement of energy conservation and it is used to relate absorption in a object to incident fields but is often misunderstood and misinterpreted. According to Poynting's theorem, if *S* is any closed mathematical surface and volume V is the volume inside S, then

$$\frac{\partial}{\partial t} \int_V W_c + cE \cdot E + \mu H \cdot H)\, dV + \phi_S\, E\, x\, H \cdot d_{S-\sigma} = 0 \qquad (23)$$

where W_c is the energy possessed by charged particles at a given point in V

E is the energy stored in the E-field at a given point in V μH.

H is the energy stored in the H-field at a given point in V.

A closed surface is any surface that completely encloses a volume. The integral over the volume V corresponds to a sum of the terms in the integral over all points inside V. Thus the integral over V correspond to the total energy inside V possessed by all charged particles and that stored in the E- and H- fields. The term of the left, then, is the time rate of change of the total energy inside V, which is total power. The term on the right is an integral over the closed mathematical surface enclosing V. For convenience, if we let

$$P = E X H \tag{24}$$

where P is called the Poynting vector.

The Poynting vector is useful in understanding energy absorption, but the Poynting theorem applies only to a closed surface and the volume enclosed by that surface. The Poynting vector was used to calculate the power density of the radiation from the mobile phone antennae in this work.

Radiation from a Generalised Localised Source

If we consider the general problem of the radiation from a localized system of charge and current densities ρ(x_1 t), J(x_1 t), and recognize that we may make a Fourier time analysis to obtain a superposition at

$$\rho(x_1 t) = \rho(x)e^{-iwt} \tag{25}$$

$$J(x_1 t)=J(x)e^{-iwt} \tag{26}$$

Then working for convenience in a Lorentz gauge one has

$$A(x,t) = \frac{\mu_o}{4\pi}\int d^3x'\int dt'\frac{J(x',t')}{|x'-x|}\delta(t'+\frac{|x-x'|}{c}-t) \tag{27}$$

From which it follows that

$$|x - x'| = \left[(x - x')^2\right]^{1/2}$$

$$= \left[n^2 r^2 - 2rn \cdot x' + x'^2\right]^{1/2}$$

$$= r - n \cdot x' + ..., \qquad (31)$$

Where x = nr and the omitted terms are proportional to higher powers of $|x'|/r \leq \frac{d}{r}$ Because the source is small, we may approximate further by neglecting all but the first contributing terms in the power series and in general will then obtain

$$A \approx \frac{\mu o}{4\pi} \frac{e^{ikv}}{r} \int d^3 x' J(x') \qquad (32)$$

$$= \frac{\mu_o}{4\pi} \frac{e^{ikr}}{r} \int d^3 x' x' [\nabla' J(x')]$$

and integration by parts

$$= \frac{\mu_o}{4\pi} \frac{e^{ikr}}{r} \int d^3 x' x' (i\omega) \rho(x') \qquad (33)$$

using the continuity equation

$$= \frac{\mu_o}{4\pi} \frac{e^{ikr}}{r} i\omega p, \qquad (34)$$

$pe^{-i\omega t} \equiv \int d^3 x' x' \rho(x') e^{-i\omega t}$ is the electric dipole moment of the source.

The dominant contribution to the fields in the far zone for a small source thus comes from the (oscillating) electric dipole moment. If the source were indeed just an oscillating dipole, the above expression for the vector potential would be exact. It is interesting to see what we get by a similar calculation using the scalar potential. Since we have

$$\phi = \frac{1}{4\pi\varepsilon_0}\int d^3 x' \int dt' \frac{\rho(x')e^{-i\omega t'}}{|x' - x|}\delta\left(t' + \frac{|x' - x|}{c} - t\right) \quad (35)$$

An expression in power of | x'|/r is again possible. The zeroth order term obtained by replacing | x'-x| by r is

$$\phi_{monopole} = \frac{1}{4\pi_{Eo}}\int d^{3'} x' \frac{\rho(x')e^{-iwt'}}{r}, \quad (36)$$

With t'=t-r/c. But this is just the coulomb potential produced by a change $Q = \int d^3 x' \rho(x', t')$ placed at the origin, and this total change is constant, i.e.

$$\phi_{monopole} = \frac{\phi}{4\pi E_o}\frac{1}{r} \quad (37)$$

and there is no resultant radiation in zeroth order, but the dipole terms enter in the next order approximation.

Radiation from an Antenna

We will consider as a further example the radiation field from a centre-fed linear antenna. Assuming that the antenna is thin, and that radiation losses are small, the current density to the antenna may be represented by

Antennas couple electromagnetic radiation and transmission line for transmission and reception.

$$\rho\left(W\,m^{-2}\right) = G(\theta,\phi)\cdot\frac{\rho T}{4\pi R^2} \qquad (44)$$

Radiation intensity I(f, θ, ϕ) received from blackbody at temperature T is

$$I(f,\theta,\phi) = \frac{2KT}{\lambda^2}\left[Wm^{-2}\,H_E^{-1}\,ster^{-1}\right. \qquad (45)$$

From principle of detailed balance of reciprocity and thermal equilibrium says that within dΩ,

Power out = Power in

Antenna radiates $P(f,\theta,\phi)\left[WH_E^{-1}\right]$ into dΩ, so

$$Power\,out = P(f,\theta,\phi)\,d\Omega\,df = \left(\frac{kTdf}{4\pi}\right)G\,d\Omega \qquad (46)$$

Antenna receives from dΩ

$$Power\,in = \frac{1}{2}\,\frac{2kT_B(\theta,\phi)}{\lambda^2}\,df\,d\Omega\,A(f,\theta,\phi) \qquad (47)$$

In thermal equilibrium T = T_B (f,θ, ϕ); then equating radiation and reception yields

$$G(f,\theta,\phi) = \frac{4\pi}{\lambda^2}A(f,\theta,\phi) \qquad (48)$$

This assumes if T_B< kT and that powers superimpose i.e. that the T_B (θ, ϕ,) signal $\bar{E}$ (t) is uncorrelated with that for T_B (θ_2, ϕ_2).

Antenna Temperature T_A

$$UT_A(WH_E^{-1}) = \int_{4\pi} A(\theta,\phi)I(\theta,\phi)d\Omega \quad (49)$$

$$Since\ I = \frac{2kT_B}{\lambda^2}\cdot\frac{1}{2}\ for\ thermal\ radiation$$

$$Therefore\ T_A = \frac{1}{\lambda^2}\int A(\theta,\phi)T_B(\theta,\phi)d\Omega$$

$$= \frac{1}{4\pi}\int G(\theta,\phi)T_B(\theta,\phi)d\Omega \quad (50)$$

The Antenna temperature contributes to overall temperature changes due to the RF radiation.

In this study temperature changes within the human head was calculated using mathematical model. Experimentally, a tissue equivalent phantom was used to estimate the temperature changes in the human head.

Base station characteristics

In Ghana, the first generation mobile phones which used the analogue Total Access Communication System (TACS) were deployed in the 1990s. During the period there was only one operator Millicom Ghana Ltd and the number of mobile phone users was a few thousand much less than the figure today. The TACS systems are still in existence; operated by only one operator – Kasapa Ltd, however the number of users are not significant. The company is at moment introducing the CDMA system.

The second generation systems based on the digital Global System for Mobile Telecommunication (GSM) was introduced in Ghana in the late 1990s and early 2000s. These systems require more sets of antennas to be installed at existing radio sites; however, increasing usage of mobile phones quickly led to new sites being required. At the moment there are four mobile phone operators in Ghana.

Third generation networks using the Universal Mobile Telephone System (UMTS) are planned for the future.

This work covers 50 sites visited during the field work. Details of radiated powers, antenna characteristics and other parameters were obtained from the operators.

Principles of cellular radio networks

Mobile phones communicate by radio signals passing to and from antenna mounted on the phone and antennas connected to the base station. Mobile communication networks are divided into geographic areas called cells, each served by a base station (Figure 2). Mobile phones are the user's link to the network. The system is planned to ensure that mobile phones maintain the link with the network as users move from one cell to another.

The radio link from the phone to the base station is known as uplink and carries the speech from the mobile phone user. A separate radio link from the base station to the phone is know as downlink and carries the speech from the person to whom the phone user is listening.

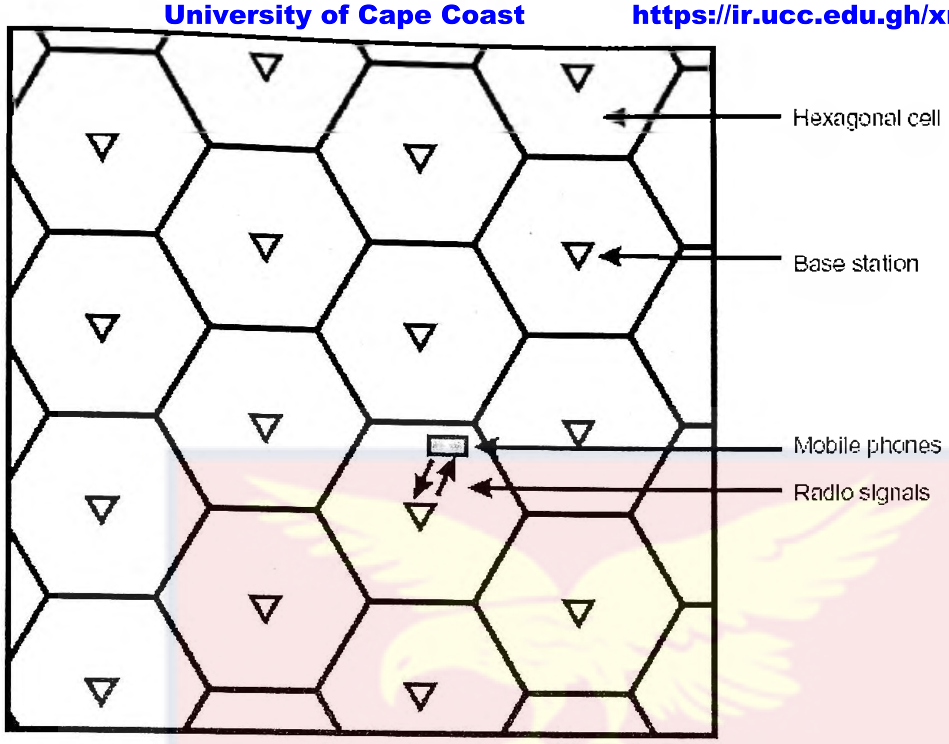

Figure 3: Network of Base Stations at the centre of hexagonal cells

Figure 4: Example of a base station's coverage area

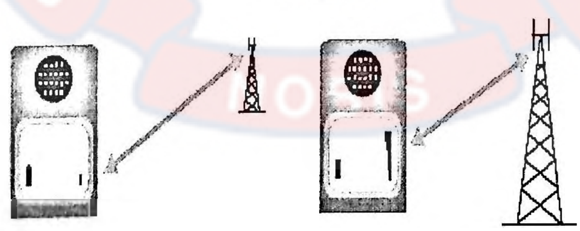

Figure 5: Signal strength is impacted by a number of factors but proximity to a base station is one of the most important.

The antennas connected to base stations tend to be mounted high above ground level because the radio signal would be blocked by buildings, trees and other obstacles if the antennas were nearer the ground. Antennas used with macro cellular base stations are generally placed between 15 and 50 m above ground level because they are designed to provide communications over distances of several kilometres. However, microcellular base stations have their antennas mounted nearer ground level as communications are only carried out over distances of a few hundred metres. Antennas tend to be mounted directly on existing structures, such as buildings, when this is convenient, but ground based lattice towers, shorter masts mounted on roofs, and lamp-post type system are also used.

Coverage and Directivity

The strength of the transmitted signal falls off rapidly with distance from base stations and mobile phones, but certain minimum signal strength is required for adequate reception. The current generation of GSM base stations cannot communicate over distances greater than 35 km because the delay in receiving radio signals becomes too great. However, the decline of signal strength with distance places a practical limit on coverage of around 10 km.

The use of a number of base stations to provide complete coverage of an area of land is illustrated by Figure **3.** The Figures 2 and 3 show how the area covered by each base station can be regarded as a hexagon, if there is a fixed distance between neighbouring base stations. The location of base stations is influenced by many factors and so cells vary in shape and size.

RF EME from a typical GSM Mobile Phone

The considerations in this subsection are restricted to the fields produced by GSM mobile phones. The maximum powers that 900 MHz GSM mobile phones are permitted to transmit by the present standards are 2W and for 1800Hz maximum power is usually 1 W. When TDMA is used, the average powers transmitted by the phone are never more than one-eighth of this maximum value (0.25W) and are usually further reduced by a significant amount due to the effects of adaptive power control and discontinuous transmission. Adaptive power control means that the phone continually adjusts the power it transmits to the minimum needed for the base station to receive a clear signal. Discontinuous transmission refers to the fact that the power is switched off when a user stops speaking.

The level of radiation at call setup is much larger than that during conversation. During this phase the phone starts by checking all control channels in order to determine the substation with the strongest signal and hence will give the best connection Abdelati (2005). Then the phone sends the origination message which is a very short message (about 0.25 second). After the cellular service provider verifies that caller is valid, the base station sends a channel assignment message to the phone. This message informs the phone on which channel the conversation will take place. Consequently, the phone turns to the assigned channel and begins the call. At this step, the ring back signal or busy signal is heard. Both of these are transmitted by the base station as an audio signal just like the voice of the person on the destination. An experiment was done to highlight the variation of the radiation levels during the call progress. The electric field at a point 1 cm from a typical phone is measured. The result is shown in Figure 5. As indicated earlier in this subsection, the magnitude of the signal may vary depending on the phone model and its location relative to the base stations. However, the experiment provides deeper insight knowledge and concludes with some advice of keeping the phone away from our head during call setup.

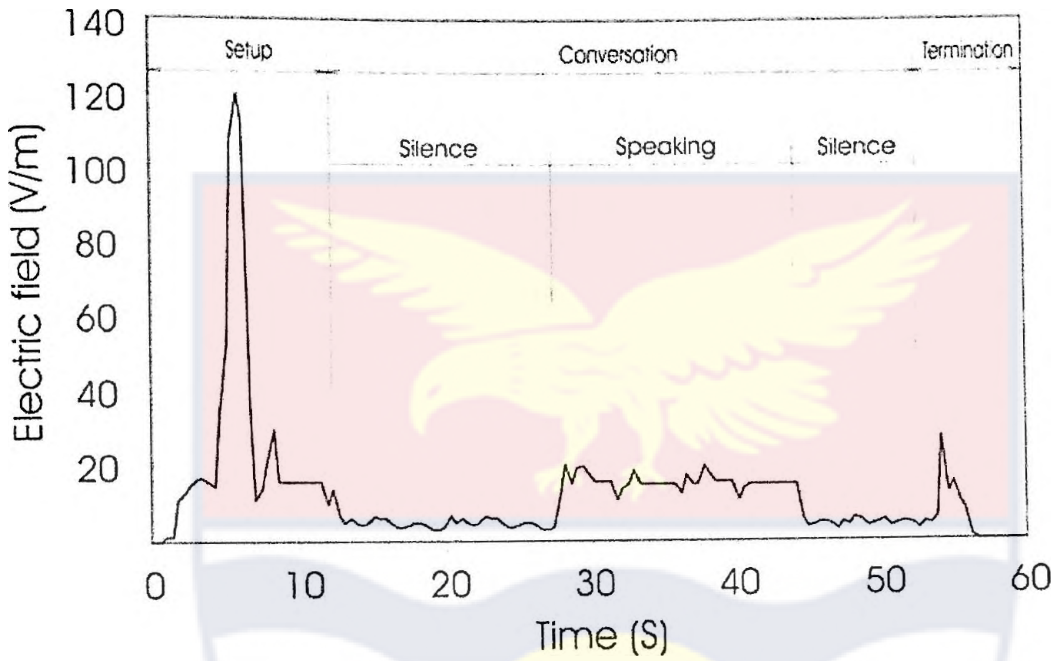

Figure 6: Electric field levels emitted from a typical GSM phone.

CHAPTER FOUR

MATERIALS AND METHODS

Introduction

In this chapter the materials and methods used for the different measurements made in this work have been described. Measurements made were:

i) The Magnetic flux and Electric field intensity at distances near and far away from mobile phone base stations at 50 sites across Ghana as shown in Figure 7.

ii) The power densities of some mobile phone handsets used in Ghana

iii) The specific absorption rate near 50 commonly used mobile phone handsets.

iv) Temperature changes inside tissue equivalent phantom.

Apart from the description of methodology, the uncertainty estimation technique has also been described.

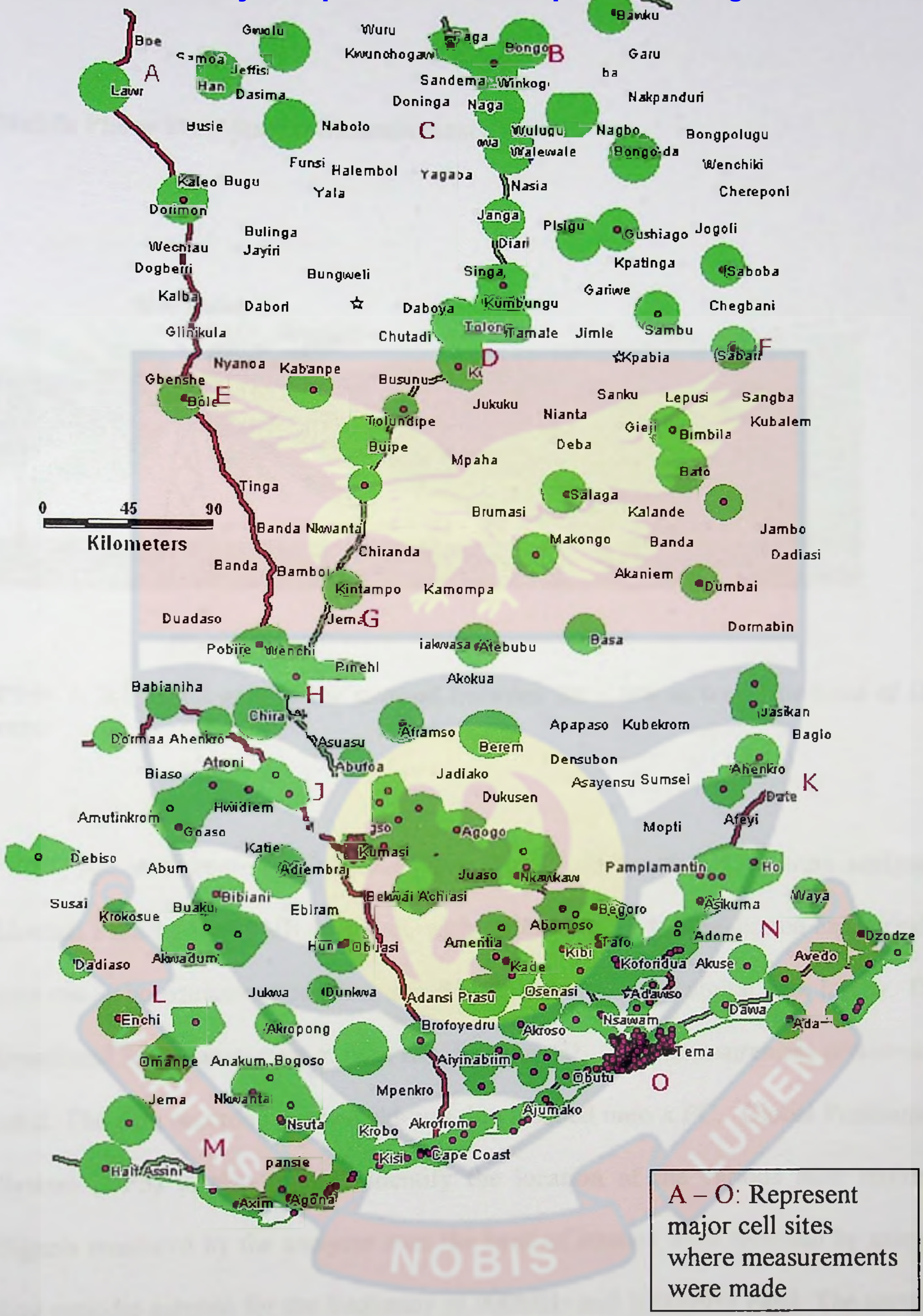

Figure 7: Map of Ghana showing mobile phone base station sites where the measurements were taken

Source: Ghana Telecom Company, 2005

Mobile Phone Base Station Measurements

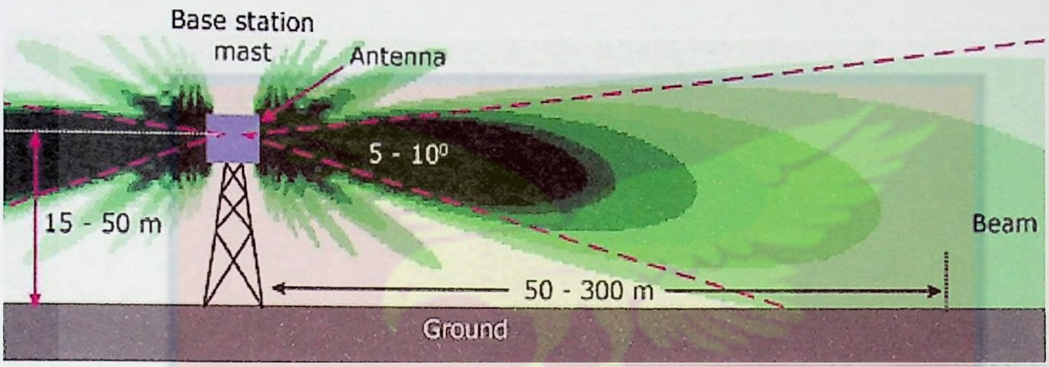

Plate 4: RF EME gets to the ground between 50 – 300 m from the base of the mast

All measurements were made using the Professional RF Spectrum analyser- Hewlett Packard HP8594E spectrum, with a Chase UPA6108 calibrated log periodic antenna. The equipment consists of a RF probe couple to a digital data logger. The broadband RF measurement at each site, Holaday HI – 4000 measurement system was used. The data recorded in the field was downloaded unto a PC. Global Positioning System (GPS) is also used to identify the location of the various base stations. Signals measured by the analyzer over the band of interest were recorded by using a Log periodic antenna for the frequency of 900MHz and 1800MHz band. The antenna was calibrated to determine its receiving performance. This factor is used for the calculation of Radiofrequency Electromagnetic emission.

Both Electric field strength and magnetic flux densities were measured at distance less than the wavelength of the station in question. Measurements were made at a distance less than 30m for those stations operating with the 900MHz band and 150m for those stations operating with the 1800 MHz band. The measurement were made during the day and analyzed over six minutes.

Plate 5: Typical Mobile Phone Base Station at one of the site used for studies
Source: Field Work (2005)

Measurements were made at locations that maintain direct-of-sight with RF sources, at a height of approximately 1.5m above the ground. The signals were measured during the day and peak period for the various stations. Data available at the offices of Telecommunication companies show the peak periods during the day were mid-day – 10.00 am – 1.00pm; and evening between 4.30pm and 7.30pm. Measurements were done during these periods.

The measurements were performed continuously logging the signal data for GSM mobile phone system that comes from the antenna. Measurements were performed by the analyser continuously scanning across the mobile telephone frequency band. The number of scans is dependent on the number of signals present in the band. The activity factors are average of the scan performed over a six minutes period. Higher activity factors may occur over a shorter period.

Far Field Measurements

Far field measurements were made using Tektronix model 2712 spectrum analyzer. The equipment received the radio signal to be analyzed and allows the accurate measurement of magnitude and frequency. The spectrum analyzer measures the level of received signal in the power unit decibels (dBm). Calculation of the field strength and hence power density require knowledge of receiving antenna properties and system losses. The Power density is expressed in microwatt per centimetre square ($\mu W/cm^2$). It is calculated using the electric field strength and assumes far field conditions where the wave impedance is 377Ω. Far field measurements were done at a distance between 100m and 500m from the base station.

Near Field Measurements

The equipment used is the same as those used for the far field measurement. However, for a near field situation both electric and magnetic measurements are required. Therefore both the E-field and H-field sensors were used. The measurement point for each site was chosen after a pre-survey to determine the point where the highest levels of exposure that a person might be subjected. Measurements were made for each point at 1.5 above the ground level. Three measurements were taken at each point and the spatial average of each of the three points to match the dimensions of the human body was performed. The field strength value is used further in calculating the average value of the three values obtained for each of the spatial point as expressed in the following equations:

$$E_{spatial\_average} = \sqrt{\frac{\sum_{i=1}^{3} E_i^2}{3}}, \qquad (51)$$

$$H_{spatial\_average} = \sqrt{\frac{\sum_{i=1}^{3} H_i^2}{3}} \qquad (52)$$

Field Measurements

The levels of Radiofrequency Emissions were measured according to protocol developed by Australian Radiation Protection and Nuclear Safety Agency (ARPNSA, 2002). That is:

- All signals with power densities greater than one percentage of the observed maximum for each frequency band were recorded individually.

- Paging system signal at VHF and UHF frequencies signals are intermittently, of short duration and with numerous close spaced narrow band carrier signals. Therefore, such signals were measured when observed and recorded if greater than 1% of the highest broadcast signal source. The sums of power densities in each frequency band were calculated.
- Other signals, such as emergency services (that is police, etc) and faxes were recorded when observed.
- If possible, measurements were made in locations that maintain direct line-of-sight with known RF sources at a height of approximately 1.7m above ground. Where practical, measurements antennae were positioned in open areas away from likely sources of reflections. Antennas were positioned and oriented so as to obtain maximum signal strength for the particular frequency band being measured. The above signals were measured during the day over a period of approximately one hour at a location within 500m of the base station.

Measurements of low level RF EMF below the measuring threshold of broadband hazard probes were performed using calibrated antennas and the RF spectrum analyzer (dBV/m). The field strength was calculated using the following equation:

$$dB\mu V/m = dB\mu V + AF + CL \qquad (53)$$

Where dBμV/m, is the field strength in the unit described microvolt per meter dBμV is the spectrum analyzer reading in decibel microvolt , CL is the cable loss and AF is the antenna factor. Antenna factor of value 20dB was used for all the calculations.

Field strength measurement over the 900MHz and 1800 MHz was performed using log periodic antenna adjustable dipoles. As the antenna measures the electric and magnetic field, a calculation of the equivalent density was performed. The following formula enabled the calculation of equivalent power density to be made and assumes a field impedance of 377Ω

$$P_d = \frac{E^2}{377} \quad (54)$$

$$P_d = 377.H^2 \quad (55)$$

Where E is the electric field strength in volt per metre and H is magnetic field strength in amp per metre.

In this study, measurements were performed at base stations using a dipole antenna with extended calibration to cover all the required frequencies and a spectrum analyser. The electric field and magnetic field levels were recorded with the antenna in three orientations- vertical (y), horizontal (x) and horizontal perpendicular direction (z) to the direction of the base station antenna at a height of 1.5m above the ground. The power density at each location was determined by combining the x, y, z polarization measurements. To quantify, the vertical spatial variability was made by making multiple measurements at five positions (the corners and centre) with a one square meter area in a vertical plane perpendicular to the direction of the base station antenna at the maximum location.

The power density was calibrated from x, y, and z polarization electric field measurement taken at each of the five point. The standard deviation of the five measurement positions was calculated. In order to obtain a worst case exposure the maximum of these five measured values was used in subsequent analysis. The equivalent power densities derived from the field measurements at each site were combined to give the power density at each frequency. This was repeated for all the sites investigated.

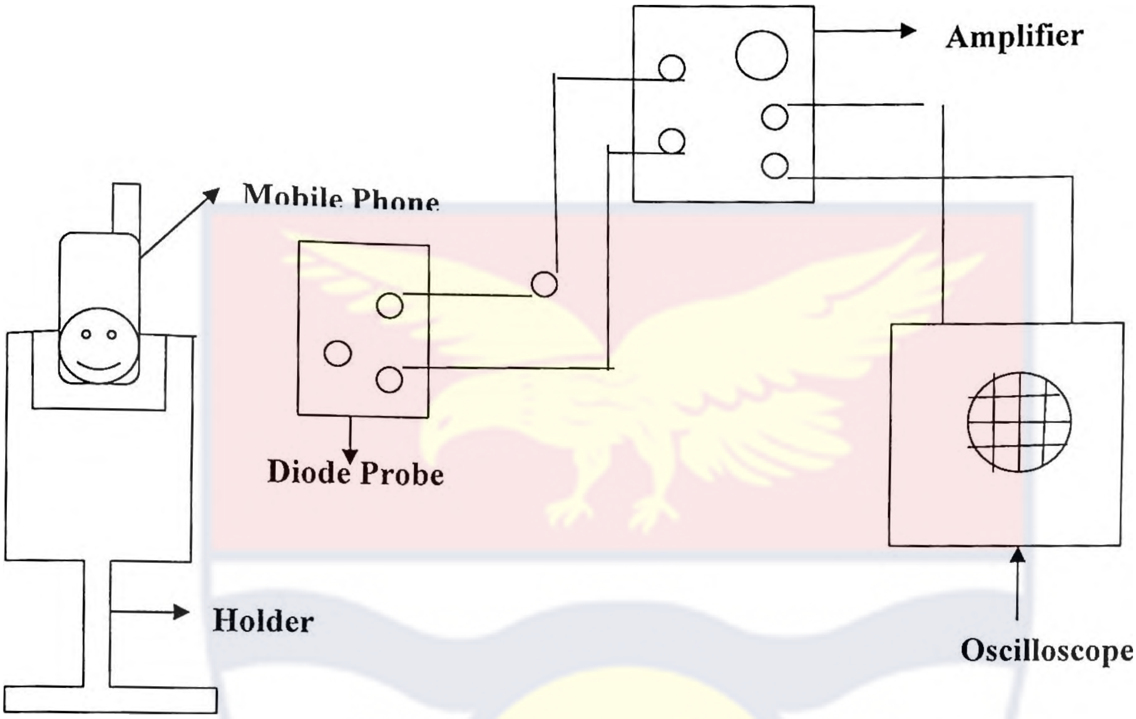

Figure 8: Experimental set -up used for the measurement of electric field intensity of mobile phone handset

Equipment used for measuring the E-field consists of two main components: a small dipole antenna that is sensitive to the presence of an E-field, and a detector that converts the signal to voltage on an oscilloscope as shown in figure 8.

The oscilloscope measured the frequencies in MHz and amplitudes in millivolts (mV) of each signal detected with the antenna. The following equation was used to convert the received voltage V_{rx} into electric field strength, E corresponding to the signal

$$E = V_{rx} \cdot F \cdot 10^{\frac{L}{10}} \qquad (56)$$

Where F is the antenna factors (m^{-1}) and L is the loss in the cable is (dB)

The intrinsic impedance of free space, η was then assumed to be equal to 377Ω so the following equation could be used to calculate the power density, S, of each signal.

$$S = \frac{E^2}{\eta} \qquad (57)$$

The value of antenna factor used for conversion of voltage values into Electric field intensity, E was 20dB.

Power densities were then calculated using Basic programme developed based on equations 10 and 57 (See Appendix A for details of Basic programme).

SAR Calculation

Using equation 22 the specific absorption rate for the different phones were calculated. The values of conductivity were calculated for dry skin using parametric model of the dielectric properties of body tissue developed by S.Gabriel (Gabriel and Lau, 1996).

In this work the Specific Absorption Rate (SAR) of the fifty (50) randomly sampled mobile telephones were determined.

The fifty mobile phones were selected from 101 different models of phones that are commonly used in Ghana.

The SAR value shows how much heat energy is absorbed in the head area from the mobile phone.

Exposure Assessment

For radio frequency waves emitted at a single frequency, a dimensional quantity known as the exposure quotient may be calibrated. This exposure quotient is expressed in terms of the measured power density $S^{measured}$ and the power density investigation level of the standard S^{inv} using the relation,

$$\text{exposure quotient} = \frac{S^{meas}}{S^{inv}} \tag{58}$$

Compliance with ICNIRP or any other guidelines can be shown using appropriate reference level. It is also possible to assess the equilibrium of all other signals to a person's exposure and the total exposure quotient. This is equal to the sum of the quotients for each signal, as given by the following expression (ARPNSA, 2002):

$$\text{Total exposure quotient} = \sum \frac{S_i^{meas}}{S_i^{inv}} = \frac{S_1^{meas}}{S_1^{inv}} + \frac{S_2^{meas}}{S_2^{inv}} + - - - - + \frac{S_n^{meas}}{S_n^{inv}} \tag{59}$$

Where n is the total number of signals. Total exposures that exceed unity indicate compliance.

Technical data obtained from operators of mobile phone in Ghana were used to calculate the power densities which were compared with the measured values.

The simplest approach that provides a conservative result was used for the calculations.

Multiple Frequency Fields

In situations whereby someone is simultaneously exposed to fields of different frequencies and depending upon the nature of exposure and the distribution of RF absorption within the body, the combined effects of exposure to multiple frequency sources may be additive. It is important that such exposures are evaluated appropriately. Consideration must be given to all relevant basic restrictions for whole body heating effects and for each smaller region or part of the body that may be simultaneously exposed. A more conservative approach to evaluate multiple frequency fields is to divide the sum of the multiple exposure levels by the reference level for the particular frequency range. The subsequent sections give the formulation for electro stimulation of the head or torso, localised body heating and whole body heating.

Electrostimulation

To prevent Electrostimulation using current density basic restrictions, the following conditions must apply at any location in the head and torso, at any instant in time:

$$\sum_{i=3kHz}^{10MHz} \frac{J_i}{J_{L,i}} \leq 1 \qquad (60)$$

Where J_i is the instantaneous spatial peak rms current density induced at frequency i

J_{Li} is the instantaneous spatial peak rms current density restriction at frequency i . when applying the corresponding reference level for peak spatial E and H, and contact current I_c, J_i is replaced accordingly. The above expression therefore becomes:

$$\sum_{i=3kHz}^{10MHz} \frac{E_i}{E_{L,i}} \leq 1 \qquad (61)$$

and

$$\sum_{i=3kHz}^{10MHz} \frac{H_i}{H_{L,i}} \leq 1 \qquad (62)$$

and

$$\sum_{i=3kHz}^{10MHz} \frac{I_i}{I_{C,i}} \leq 1 \qquad (63)$$

Measurement Uncertainty

There are several sources of uncertainty associated with the method used to measure electric field strength. The uncertainties include;

a. Electrical factors associated with the calibration of the spectrum analyzer and antenna.

b. Factor arising from surveying practices, for example positioning and handling of the antennas

The measurement uncertainty was evaluated for those measurements addressed taking into consideration each of the quantities measured. The standard uncertainty $U_{(x_i)}$ and the sensitivity coefficient c_i were evaluated for the estimate x_i of each quantity. The combined standard uncertainty $u_c(y)$ of the estimate y of the measurand is a weighted rooted sum square (r.s.s.):

$$u_c(y) = \sqrt{\sum_{i=1}^{n} (c_i^{\bullet} u_{(x_i)})^2} \tag{64}$$

The expanded measurement uncertainty u_e is calculated as:

$$u_e = 1.96 u_c \tag{65}$$

Uncertainty in the antennas used for the experiment was 1.0dB and the intrinsic uncertainty of the monitor was 2dB.

Mathematical Model for Estimating Temperature Changes in Human Tissue

When a typical mobile phone handset is place on the side of the head, the heated region is small compared with the size of the head. The heating is superficial and therefore the hypothalamus itself is not directly affected.

In this section a mathematical model based on the Pennes' Model has been described. The Pennes model was used to analyse tissue and arterial blood temperatures in the resting human forearm (Pennes, 1948). The model has been modified to describe temperature changes in the human head.

From Pennes' Model the rate of heat transfer between blood and tissue is proportional to the product of the volumetric perfusion rate and the difference between the arterial blood temperature and local tissue temperature. That is:

$$h_b = V\rho_b C_b (1-k)(T_a - T) \quad (66)$$

Where h_b is the rate of heat transfer per unit volume of tissue, V is the perfusion rate per unit volume of tissue, ρ is the density of blood, C_b is the specific heat of blood, k is the factor that account for incomplete thermal equilibrium between blood and tissue, T_a is the temperature of arterial blood, and T is the local tissue temperature where 0<k<1. From the heat equation, the rate of change in local tissue temperature is given by:

$$\rho C \frac{\partial T}{\partial t} = k\nabla^2 T + h_m + h_b, \quad (67)$$

Where ρ and C refer to tissue, k_t is the thermal conductivity of tissue, h_m is the metabolic rate. The SAR distributions have been found to be directly related to the temperature distribution. Modify the Pennes bioheat equation we have,

$$\rho_t C_t \frac{\partial T}{\partial t} = \nabla.k_t \nabla T - \omega_b C_b (T - T_{body}) + \rho SAR + M \quad (68)$$

Where ρ_t is the tissue density, C_t is the specific heat of the tissue, k_t is the thermal conductivity, ω_b is the blood flow, C_b is the specific heat of the blood, T_{body} is the temperature of the human body and M is the heat generation produced by metabolism (generally considered to be negligible). This is commonly used for large vessels. For smaller vessels, the effective conductivity model is more adapted since it deals with the conduction of the tissue and the heat transfer between pairs of blood vessels.

$$\rho_t C_t \frac{\partial T}{\partial t} = \nabla . k_{eff} \nabla T + \rho SAR + M \quad (69)$$

Where k_{eff} is the effective thermal conductivity depending on the size of the vessel, the flow and vessel, and the flow and the vascular structure.

$$\rho_t C_t \frac{\partial T}{\partial t} = \nabla . k_{eff} \nabla T - f W_b \left(T - T_{body}\right) + \rho SAR + M \quad (70)$$

where k_{eff} effective thermal conductivity replaces the intrinsic thermal conductivity. The factor f ranges from zero (0) to one (1). f is assumed to be 1 in this work assuming maximum heat flow in blood.

The solution of equation for steady state is as follows:

$$\frac{\partial T}{\partial t} = \frac{1}{\rho_t C_t} \left[\nabla K_k \nabla T - W_b C_b T + W_b C_b T_{body} + \rho . SAR + M\right] \quad (71)$$

Assuming superficial heating of the skin, the variation of T with skin depth is negligible.

For one dimensional considerations

$$\frac{\partial T}{\partial t} = \frac{1}{\rho_t C_t} \left[\left(K_k - W_b C_b\right) T + W_b C_b T_{body} + \rho SAR + M\right] \quad (72)$$

$$\Rightarrow \frac{\partial T}{\partial t} = \frac{\left(K_K - W_b C_b\right)}{\rho_t C_t} T + \frac{1}{\rho_t C_t} \left[W_b C_b T_{body} + \rho SAR + M\right]$$

Since $K_k, W_b C_b, \rho_t, C_t, \rho T_{body}$ M *are constarts*

$$Let \frac{K_k - W_b C_b}{\rho_t C_t} = p \text{ and}$$

$$\frac{1}{\rho_t C_t} \left[W_b C_b T_{art} + \rho SAR + M\right] = q \quad (73)$$

$$\Rightarrow \frac{\partial T}{\partial t} = \rho T + q \quad (74)$$

$$\rho(t) = \rho, q(t) = q$$

$$U(t) = U_c(t) + U\rho(t)$$

$$U_c(t) = Q\ell\int_{to}^{t} \rho dt = Q\ell\ \rho^{(t-to)} = Q\ell^{\rho t}$$

$$q(t) = q$$

$$Let\ T = \alpha t \qquad (75)$$

$$\Rightarrow \frac{\partial T}{\partial t} = \alpha \qquad (76)$$

Substituting (75) *and* (76) *in* (74) *gives*

$$\alpha = \rho \alpha t + q$$

Comparing coefficients

$$q = \alpha$$
$$\rho\alpha = 0$$
$$\rho = 0$$
$$U\rho(t) = qt$$

But General Solution in $U(t) = U_c(t) + U\rho(t)$

$$\Rightarrow U(t) = Q\exp(\rho t) + qt$$
$$T_{body} \leq 24^{o}C\ or\ 37^{o}C$$
$$T(t) = Q\exp(\rho t) + qt \qquad t_o = 0$$
$$37^{o}C = Q$$
$$\therefore T(t) = 37\ \exp(\rho t) + qt \qquad (77)$$

Using a computer programme written in Fortran computer language shown in Appendix B the temperature variation in human head was calculated for different SAR values at different frequencies. Parameters and constants used in the model are shown in Table 1.

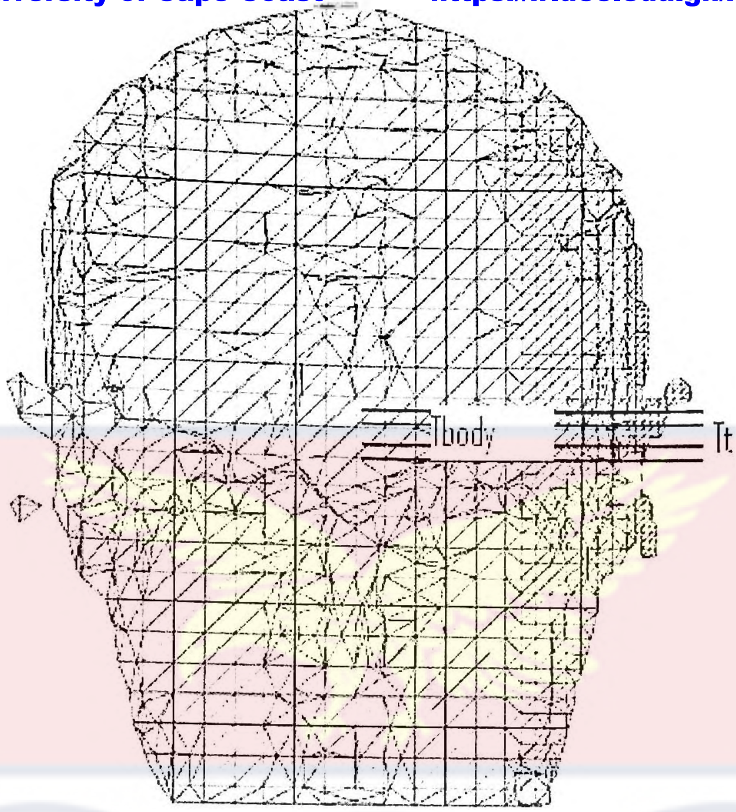

Figure 9: Head model showing temperature at different locations within and outside the head due to heat transfer

Table 1: Parameters used for calculating temperature changes in human skin

Parameter	Standard Value	Units
Blood Flow Wb	2.64	ml $100ml^{-1}m^{-1}$
Thermal Conductivity of skin (dermis) K	0.322	W/mK
Ambient body temperature T_{amb}	37.0	°C
Density of water at 37°C	994.1	Kg/m^3
Specific Heat Capacity of water at 37°C	4179	$JKg^{-1}K^{-1}$

Experimental Determination of Temperature Changes in the Human Head

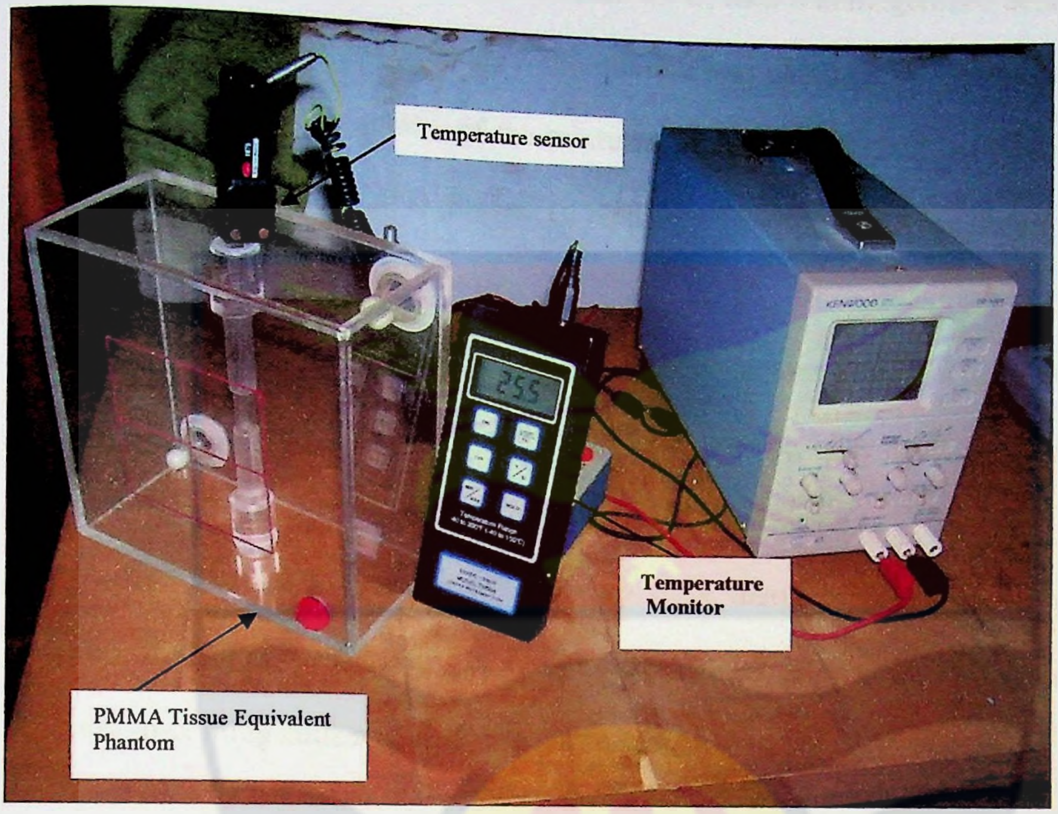

Plate 6: Set-up used for the Determination of Temperature Changes in Phantom

Source: Laboratory work (2006)

PMMA tissue equivalent head phantom was used to represent the human head. The phantom was filled with tissue equivalent fluid in order to mimic the human tissue. The tissue equivalent liquid was formulated by adopting method used by Vigneras & Bonnaudin (2001).

The tissue equivalent liquid has the following components expressed as mass percentages: De-ionised water -61.3 %; Mineral oil -12.6 %;Triton X 100(polyethylene glycol mono (4-1,1,3,3-tetramethylbutyl) phenyl ether) -25,4 % ; NaCl- 0.7 %.

Because of the difference of density between water and triton X 100 a lot of care had to be taken to formulate of the mixture. The mixture water-Triton-oil was heated very slowly for about 15 min to reach 45°C, then it homogenized delicately for about 2 min. A very homogeneous white mixture was obtained. A visual control was sufficient to verify the quality of the mixture. After about half an hour, the mixture separates in two easily visible phases. To obtain again a homogeneous liquid, it had to be mixed delicately, without heating.

A temperature sensor was placed inside the phantom as shown in the plate 6.

The temperature of the phantom was moderated to 10°C using liquid Nitrogen to ensure the small variations in temperature could be measured.

The temperature sensor is made up of a thermistor coupled to a digital monitor. The temperature changes were observed at ten seconds interval as the phone receives in-coming calls and as the phone makes calls.

CHAPTER FIVE

RESULTS AND DISCUSSION

Base Stations Results

In this section the results from fifty base stations from a number of cell sites in Ghana have been presented. The results in figures 10 to 60 show variation of the power densities with frequency of transmission.

Results in figures 61 to 66 show the level of compliance of the various base stations to the ICNIRP guidance levels for power densities at the different frequencies. Figures 67 and 68 show the variation of power density with distances from different masts.

Field Measurements and Power Density Calculations

The results of field measurements at various cell sites used for this studies show power density variation of as low as $0.01\mu W/m^2$ to as high as $10\mu W/m^2$ for the frequency of 900 MHz. At a transmission frequency of 1800MHz, the variation of power densities is from $0.01\mu W/m^2$ to $100\mu W/m^2$. The lowest power density value was recorded at sites O4 and H2 for the 900MHz frequency and the highest value at the same frequency was recorded at sites D1, E1, E3 , J8, M1, N2 and N3. The difference may account for by the location of this cell sites. Higher field levels were recorded at cell sites which are remote and serving several communities as compared to cell sites that are very close to each other. At a frequency of 1800MHz, the lowest power density values were recorded at site O4 and the highest recorded at sites D1 and D4.

The low values of field measurements at most of the cell sites do not discount the possibility of biological effects on the population. On mechanism that could lead to biological effects at these low fields is that proposed by Frohlich, and which relies upon the existence in biological tissue of a particular coherent state of mechanical vibration (Frohlich, 1980, 1986). This phenomenon cannot be rule out. There is the need therefore for further work to investigate the proposed mechanism.

A critical look at Figures 64 – 69, show very high levels of compliance with the ICNIRP limits. However at sites D7, K1, L2, M1, N2, N3 for frequency of 900MHz the level of compliance need to be improved as there were indication of deviation from the general trend. The results generally show that level of compliance ICNIRP limit was about 0.01%. These results may appear low but survey in Australia shows that exposures were 0.0021% of the ICNIRP limit (Bangay and Henderson, 2004). This is a cause for concern as exposure level in Ghana appears to be close to 20 times higher to that in Australia.

The results further show poor correlation between predicted levels base on various predictive models and measured levels. This may be due to both path loss resulting from loss of line-of-sight transmission and destructive interference resulting from multipath transmission. The spread of prediction of exposure indicate that calculated levels of RF EME do not provide an accurate prediction of exposure. It is however possible to say that most predictions will be 10 to 1000 times greater than the actual exposures.

The overall level of RF EME exposure for people living in the urban environment involves exposure to a large number of radio sources. The contribution to the overall RF EME from other sources may be an important consideration for any epidemiology study and will likely present as confounder.

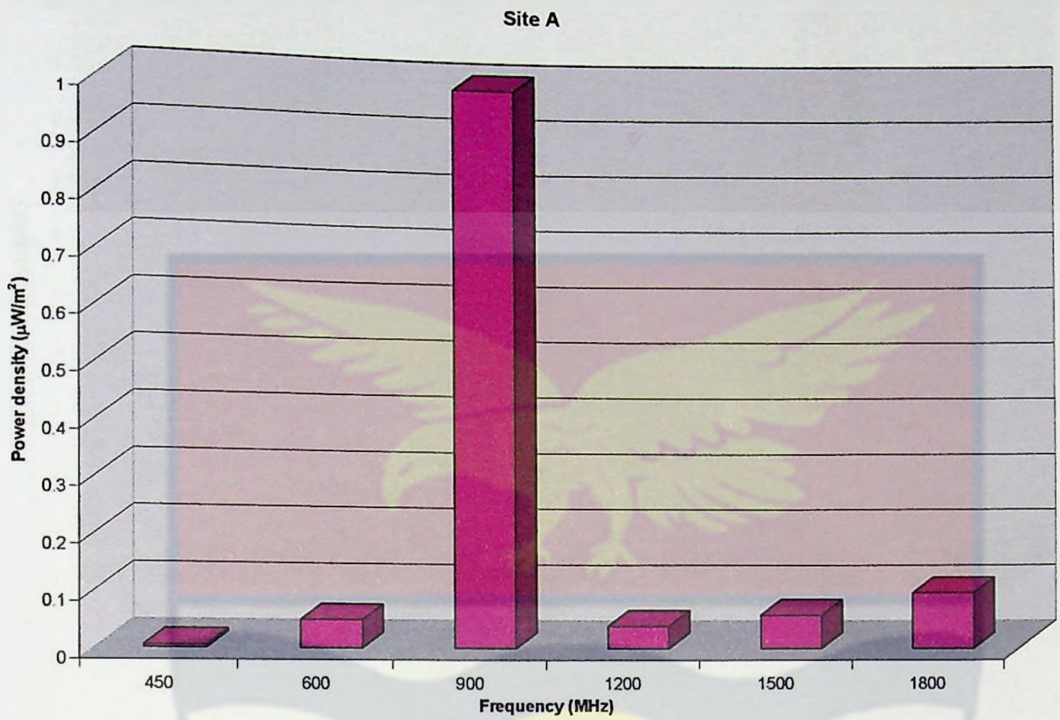

Figure 10: Power Density variation with frequency at site A

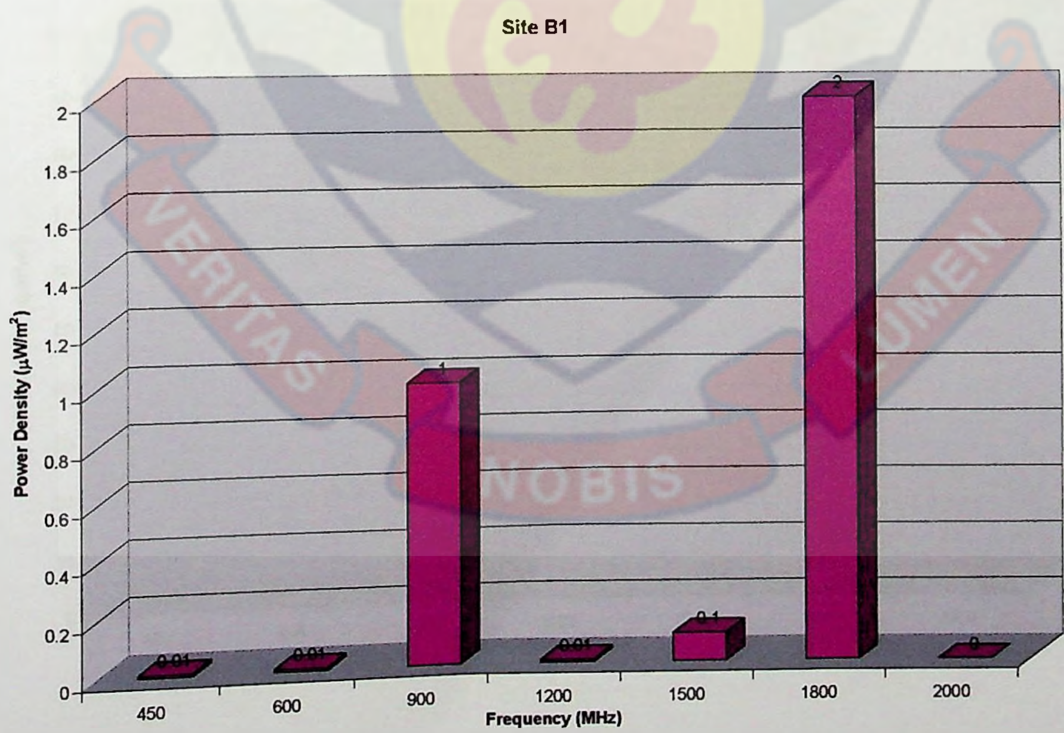

Figure 11: Power Density variation with frequency at site B1

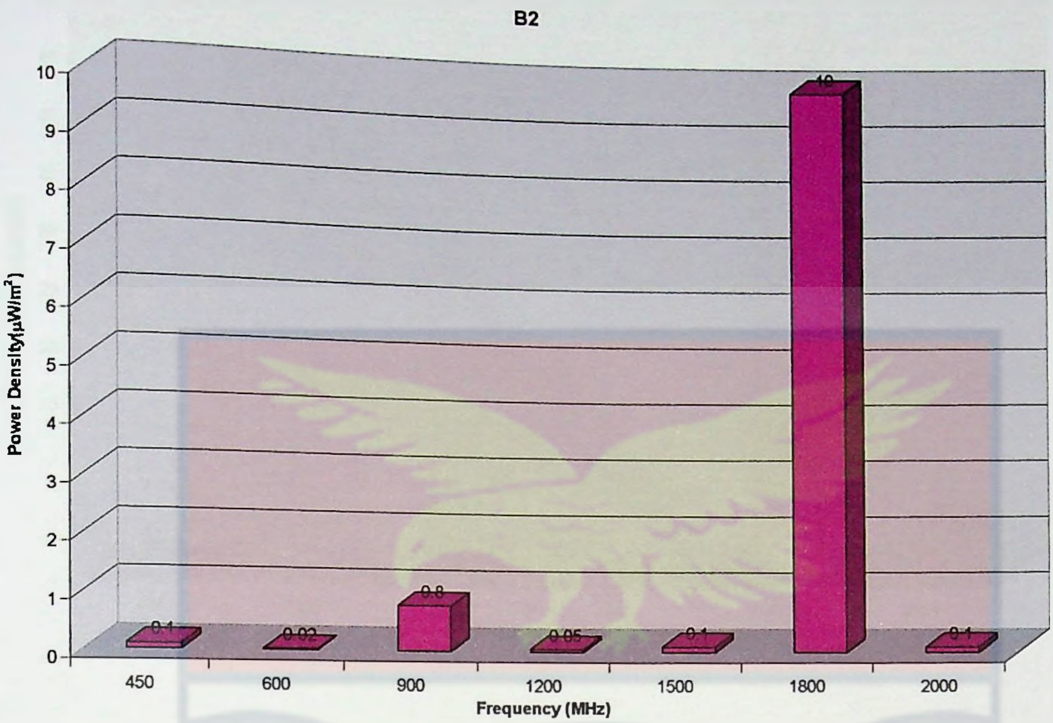

Figure 12: Power Density Variation with frequency at site B2

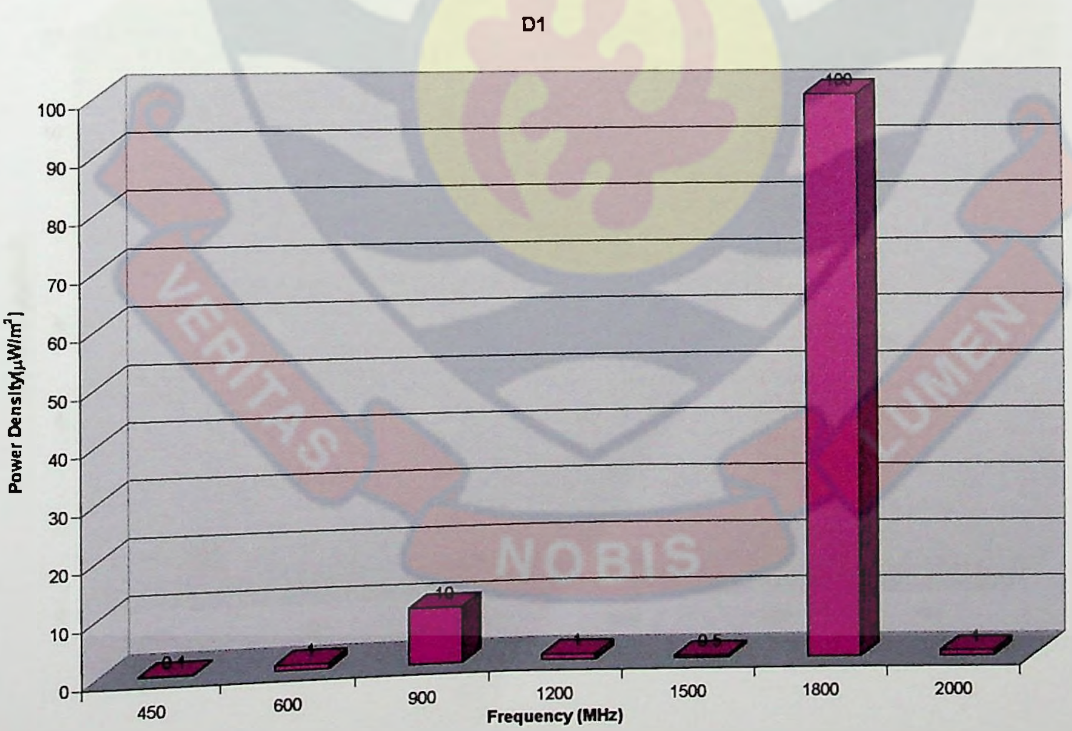

Figure 13: Power Density Variation with frequency at site D1

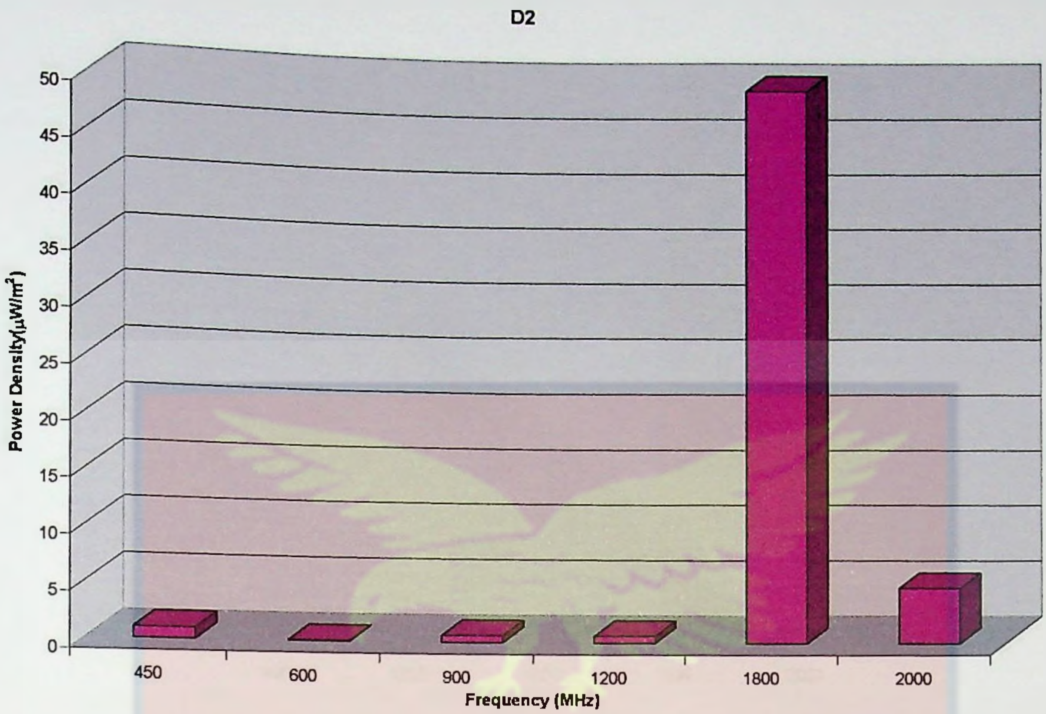

Figure 14: Power Density Variation with frequency at site D2

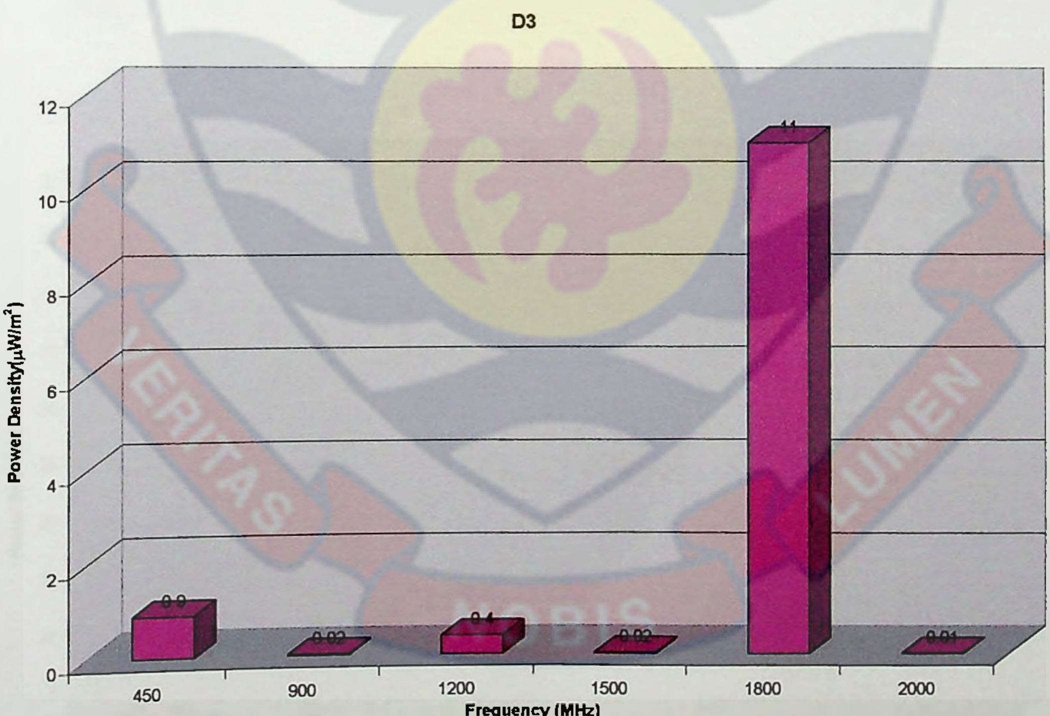

Figure 15: Power Density Variation with frequency at site D3

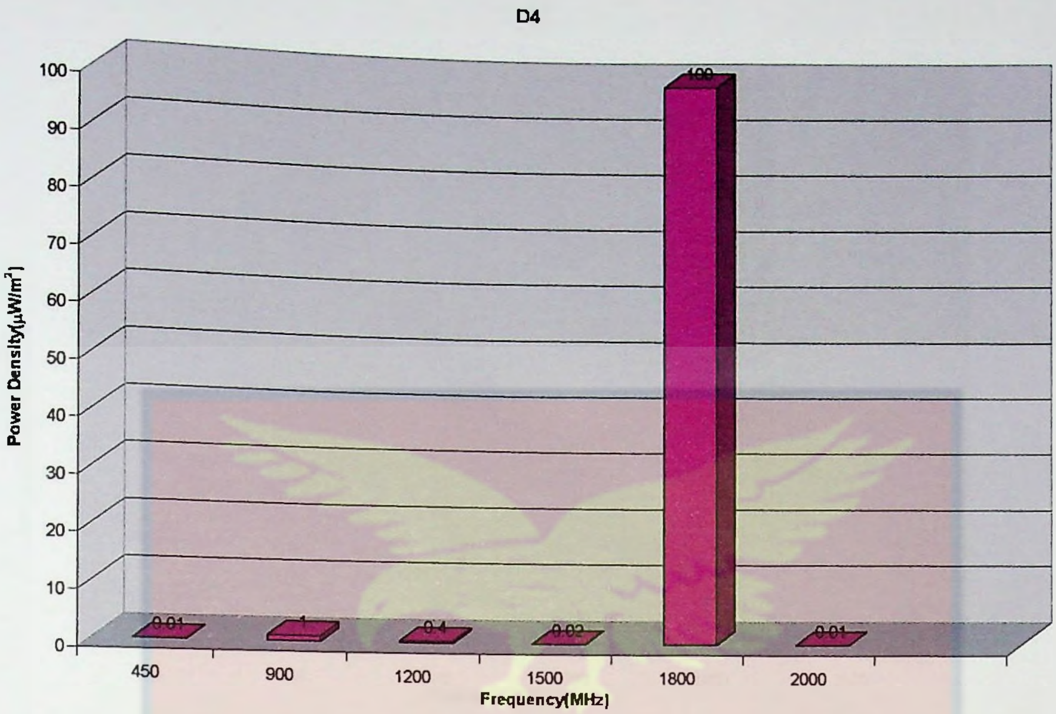

Figure 16: Power Density Variation with frequency at site D4

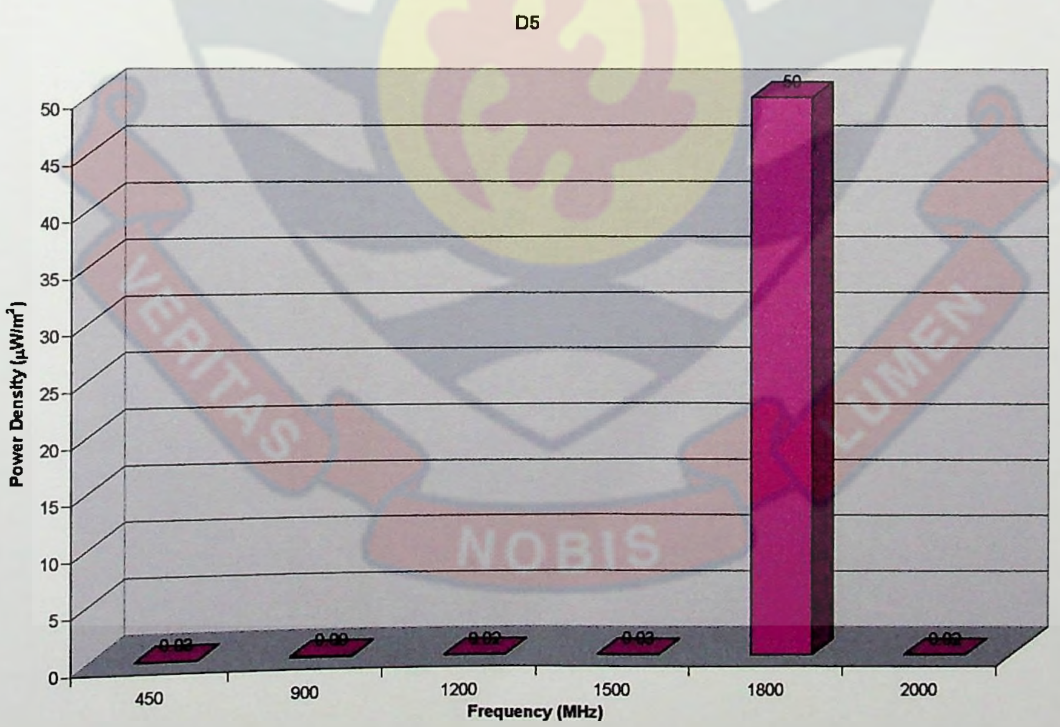

Figure 17: Power Density Variation with frequency at site D5

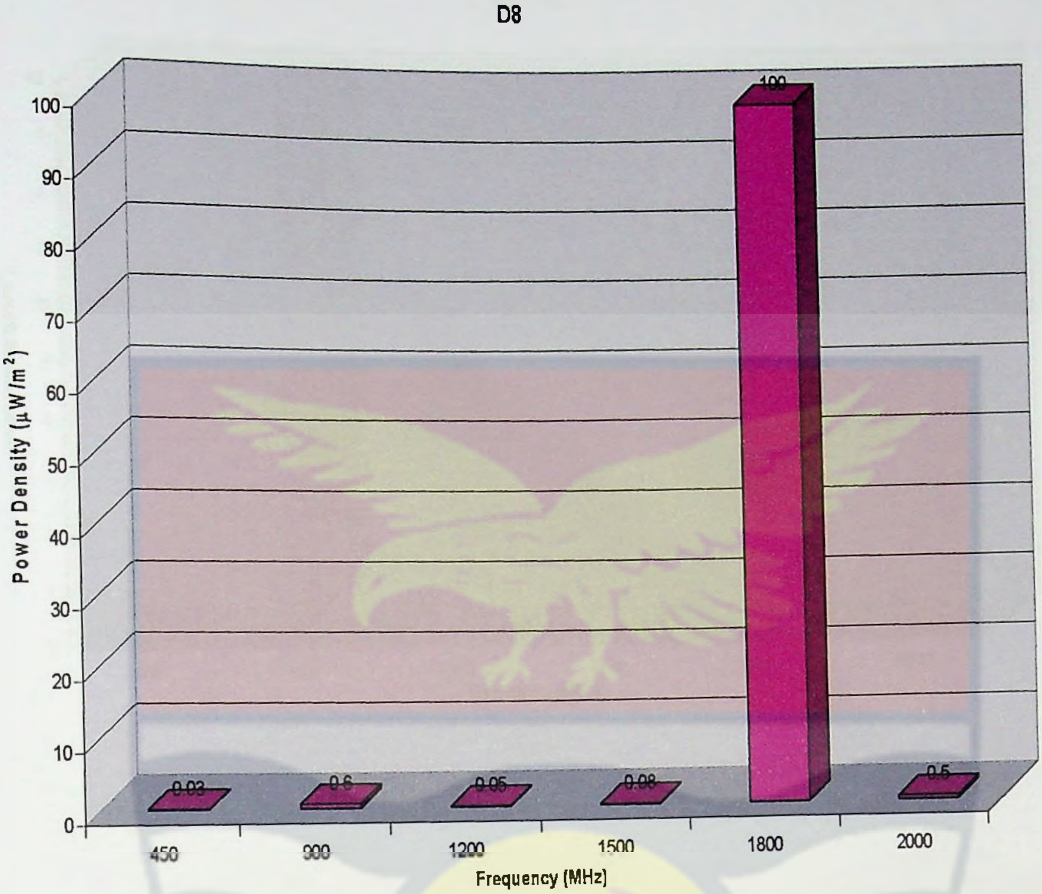

Figure 20: Power Density Variation with frequency at site D8

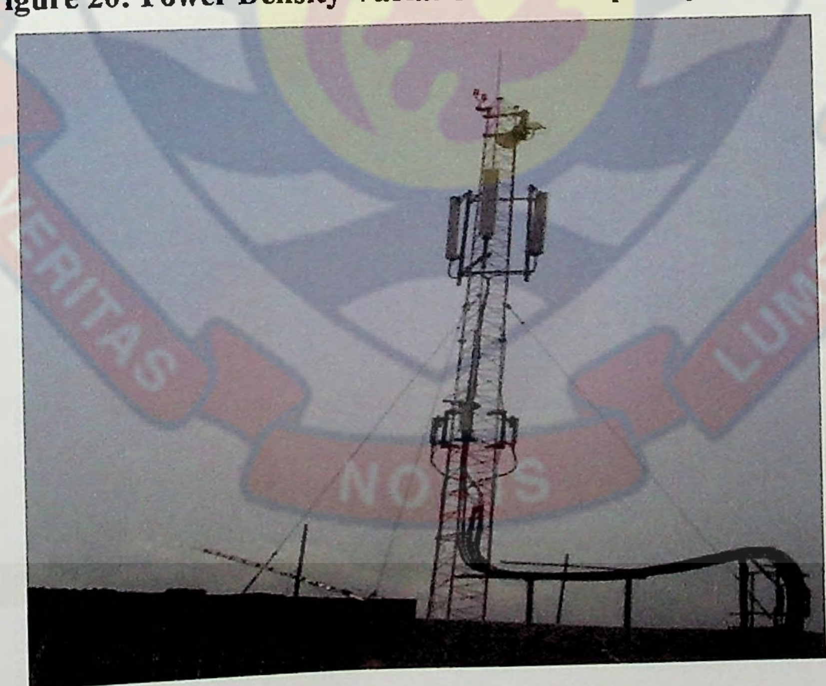

Plate 7: Three sector antennae located at site D

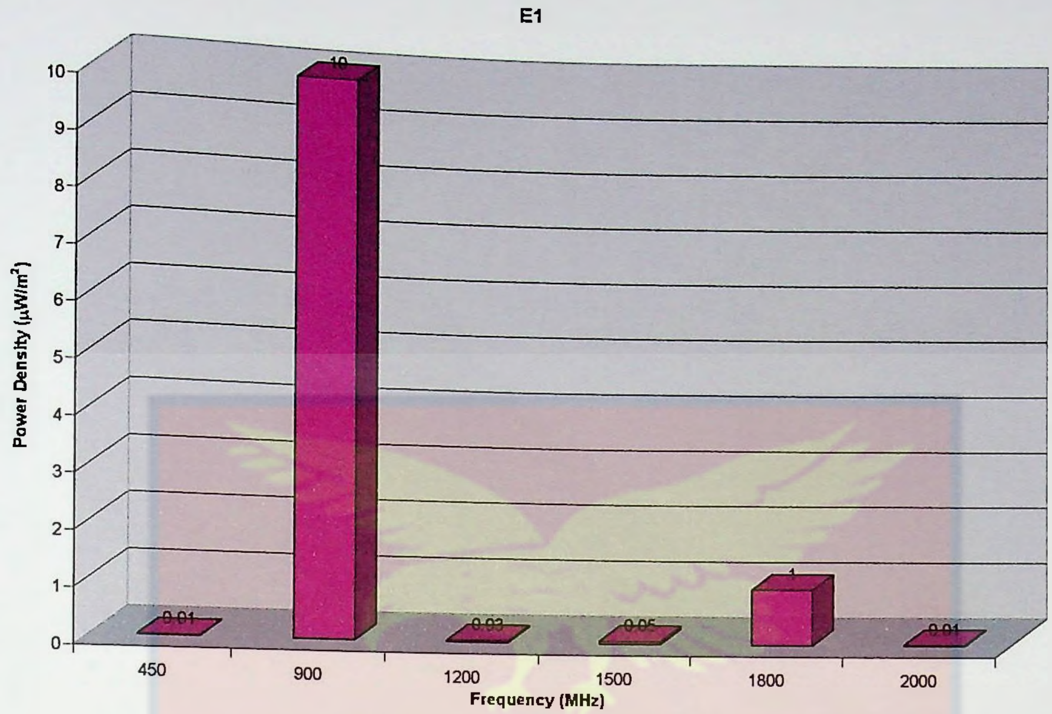

Figure 21: Power Density Variation with frequency at site E1

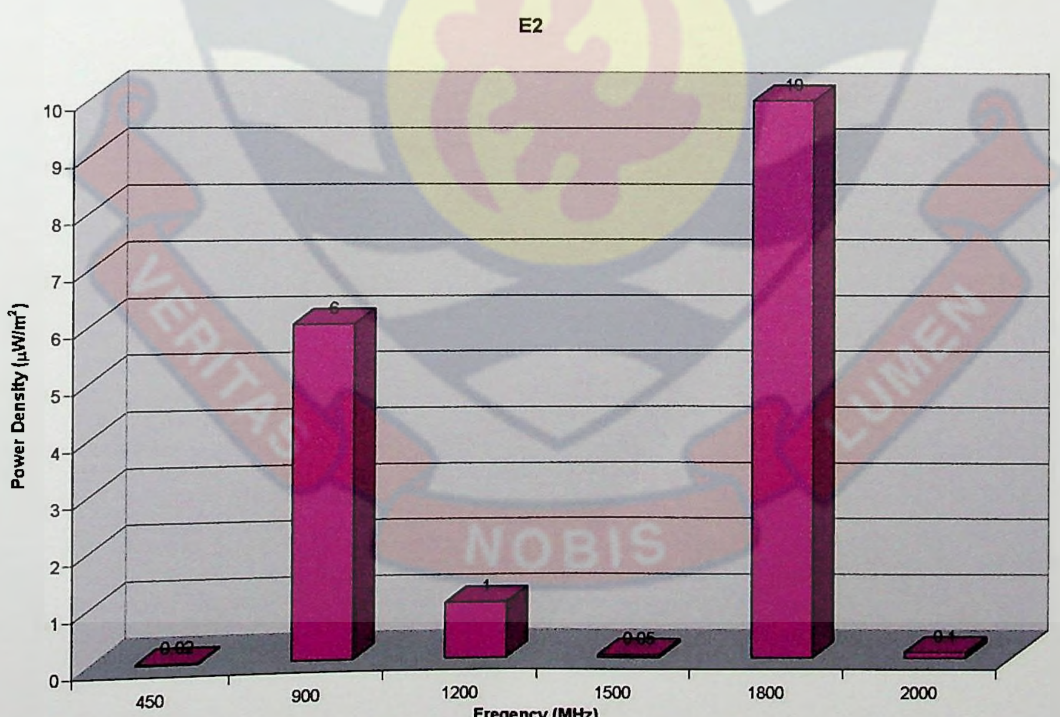

Figure 22: Power Density Variation with frequency at site E2

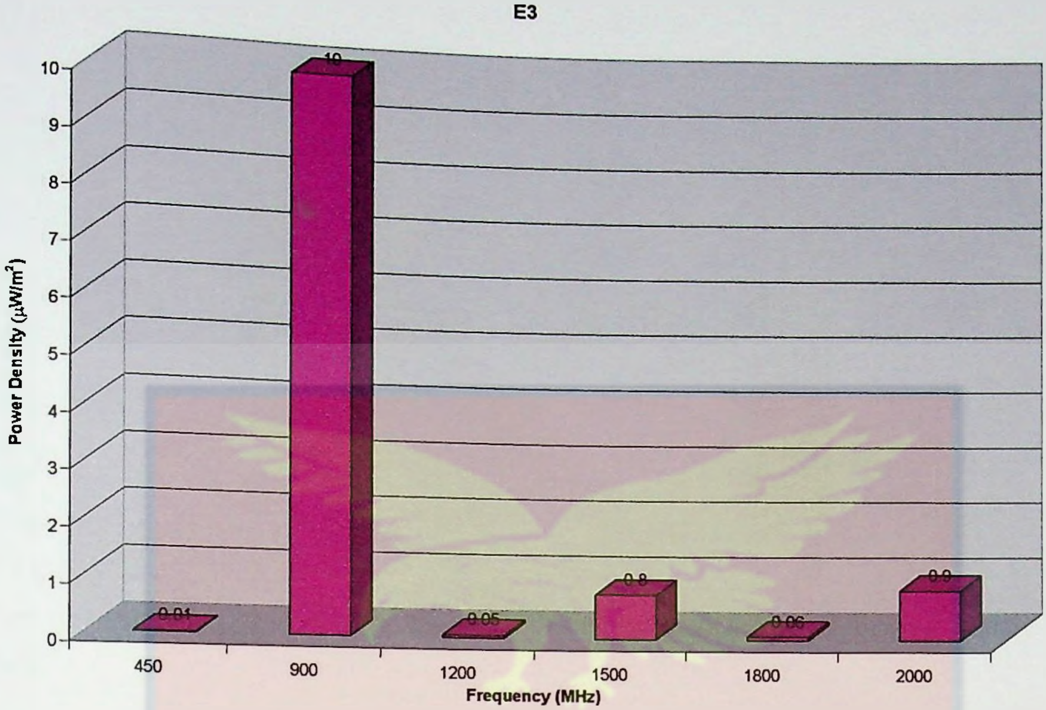

Figure 23: Power Density Variation with frequency at site E3

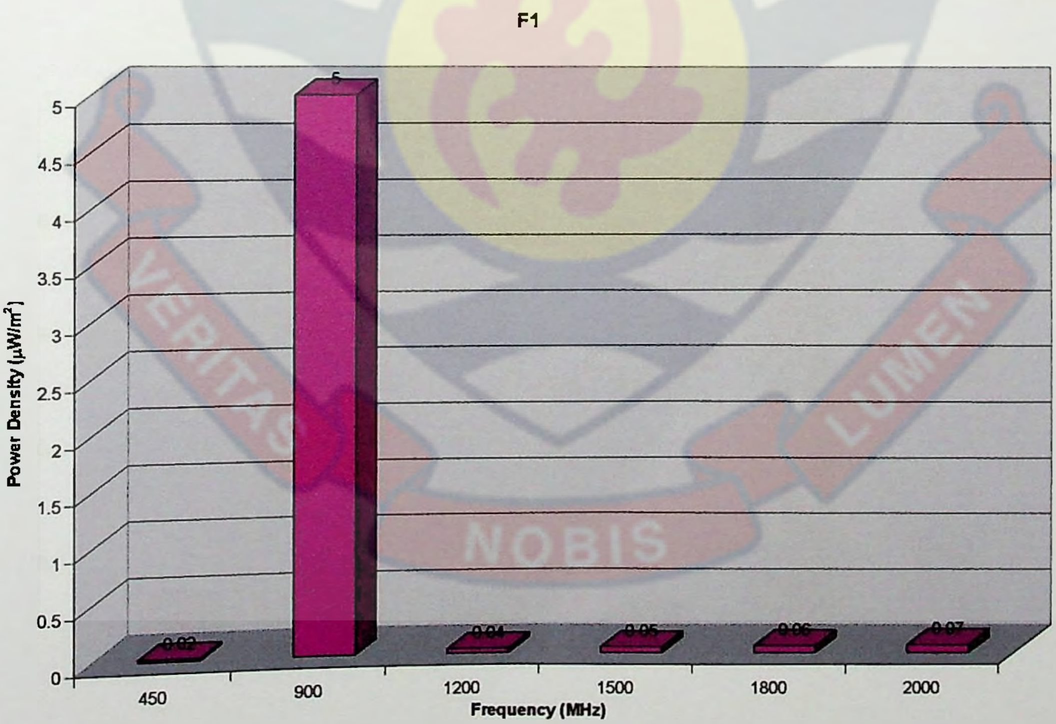

Figure 24: Power Density Variation with frequency at site F1

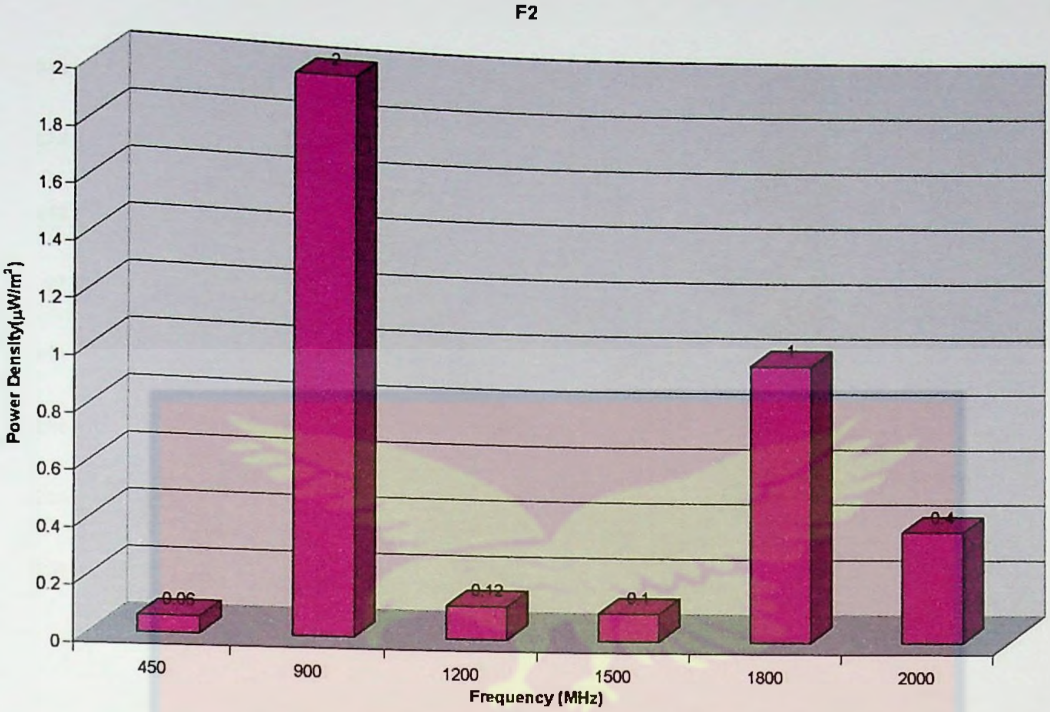

Figure 25: Power Density Variation with frequency at site F2

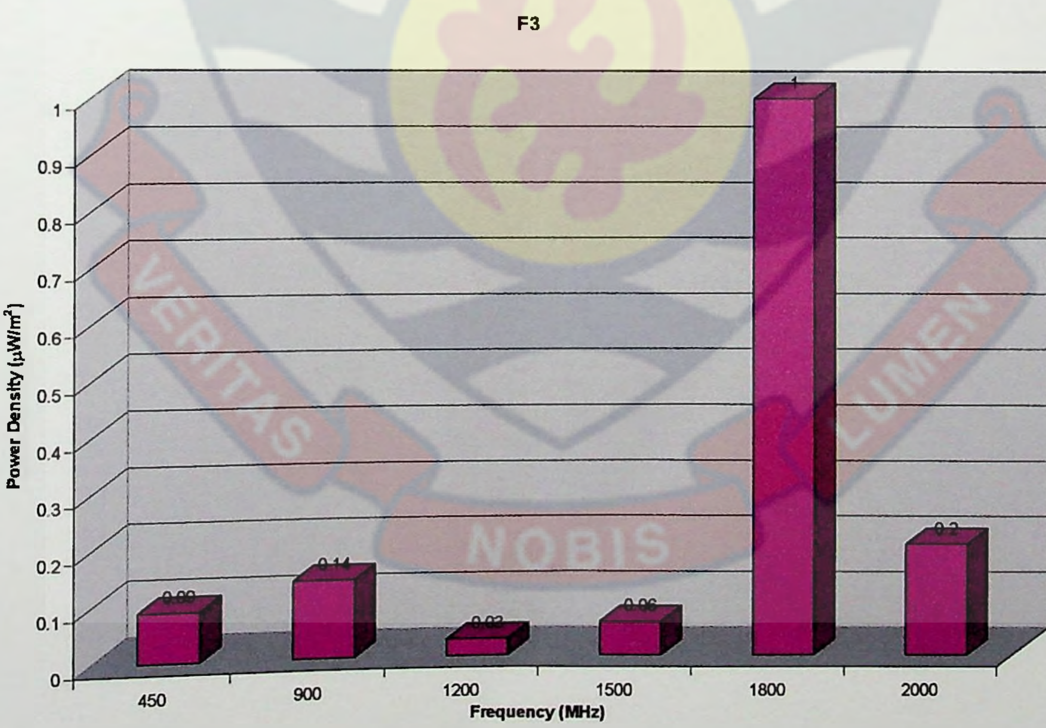

Figure 26: Power Density Variation with frequency at site F3

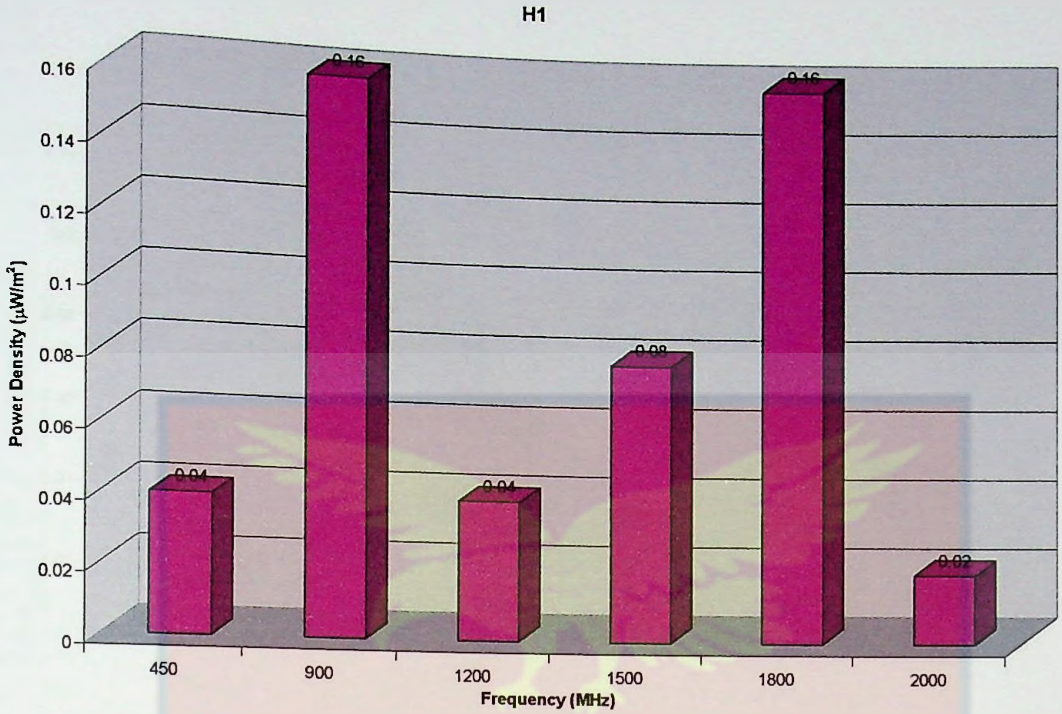

Figure 27: Power Density Variation with frequency at site H1

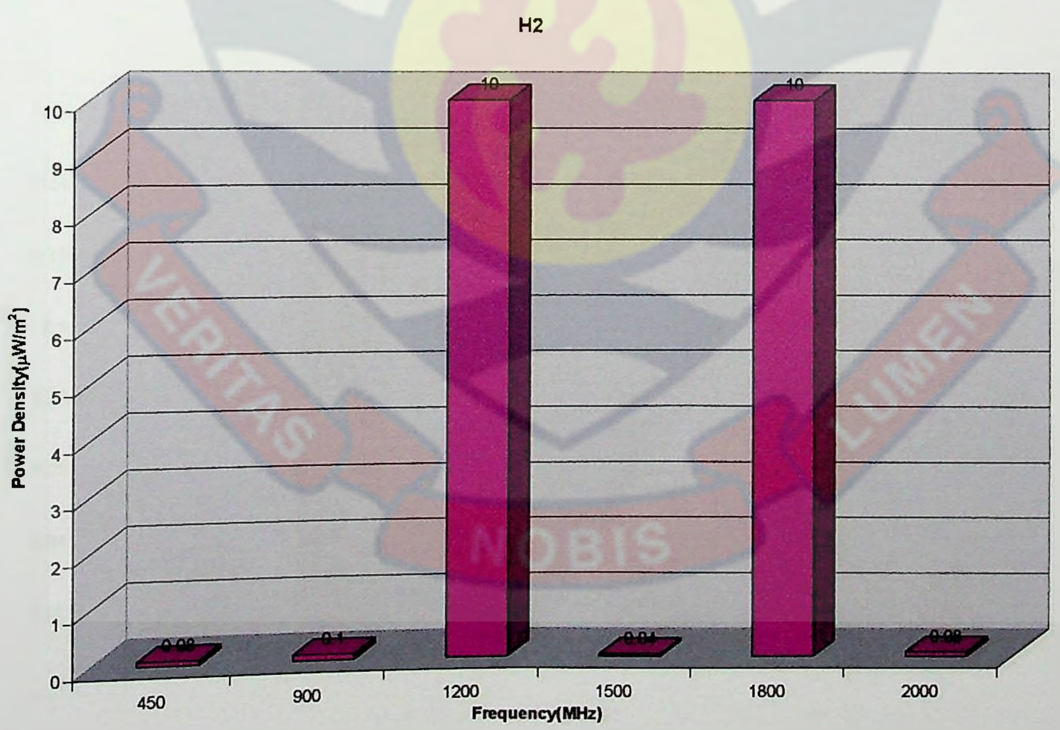

Figure 28: Power Density Variation with frequency at site H2

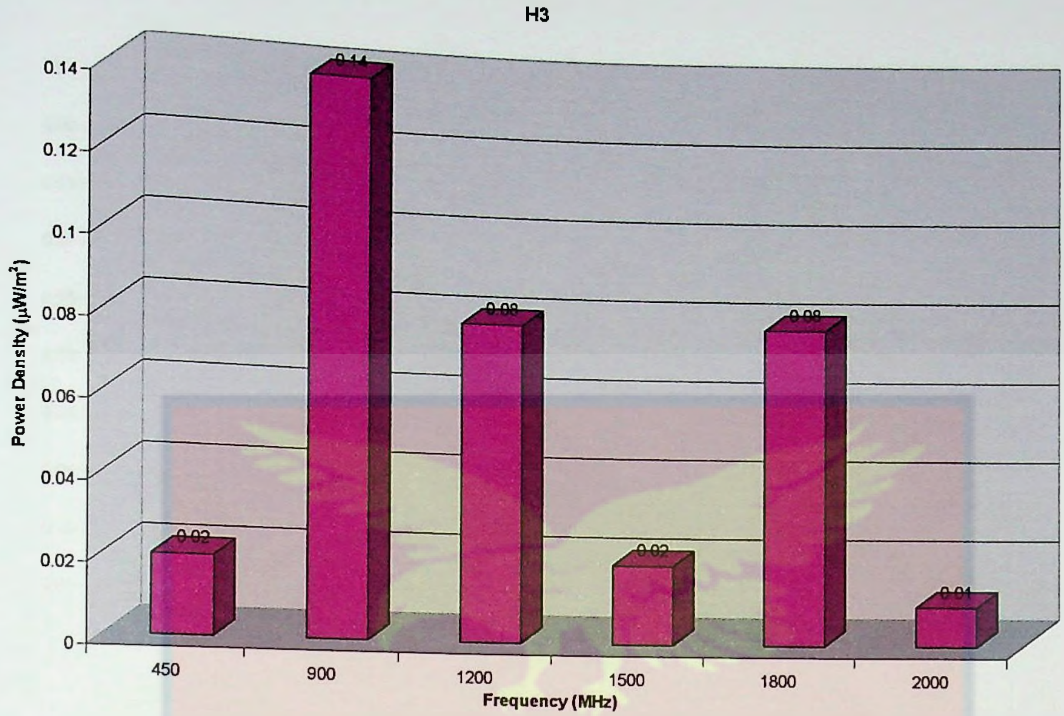

Figure 29: Power Density Variation with frequency at site H3

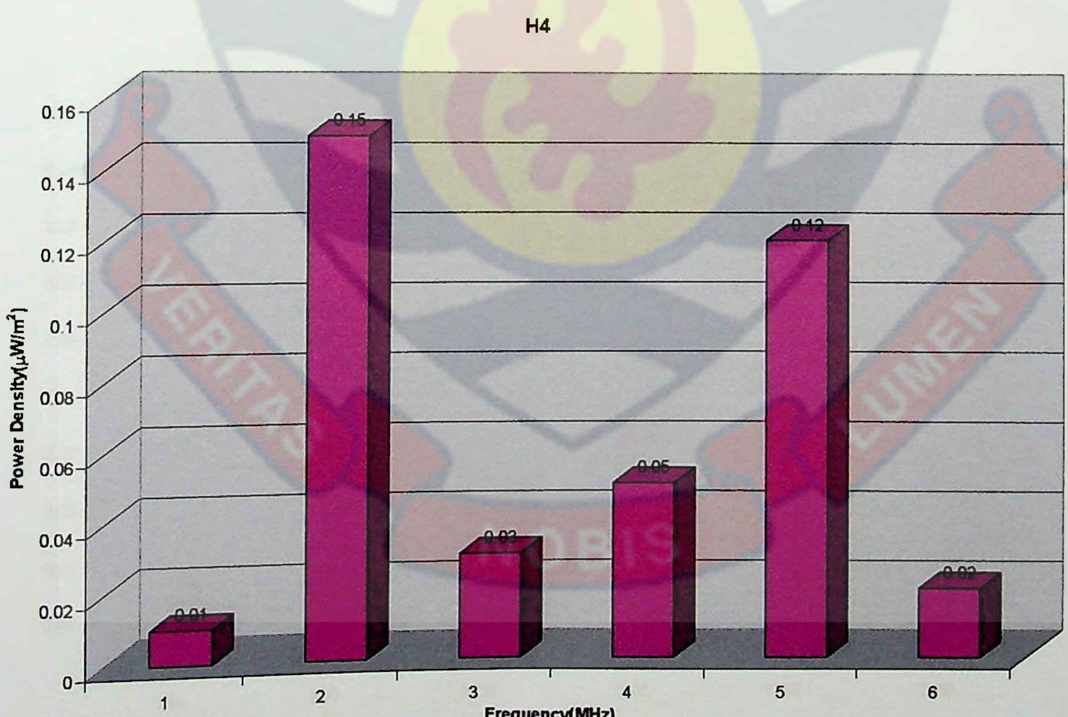

Figure 30: Power Density Variation with frequency at site H4

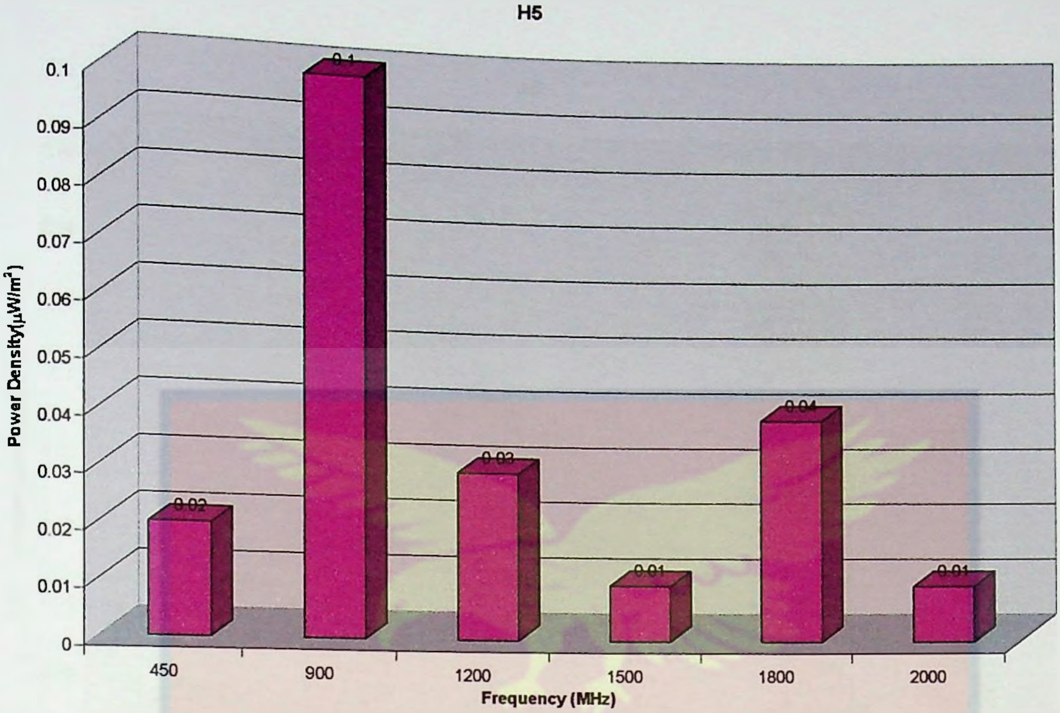

Figure 31: Power Density Variation with frequency at site H5

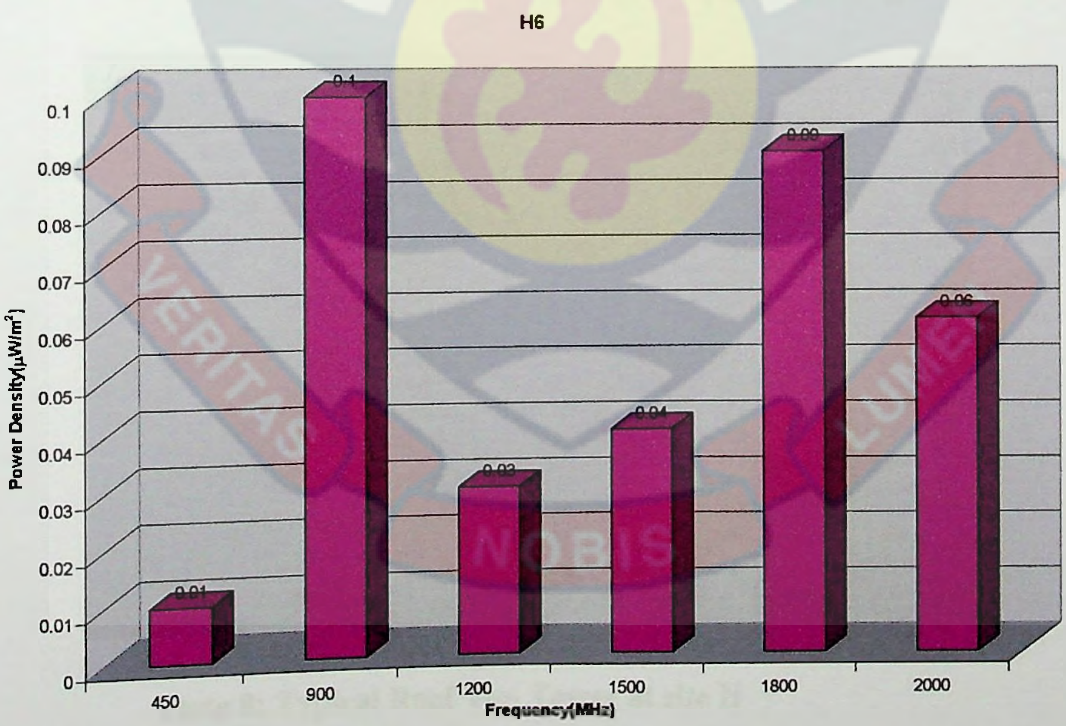

Figure 32: Power Density Variation with frequency at site H6

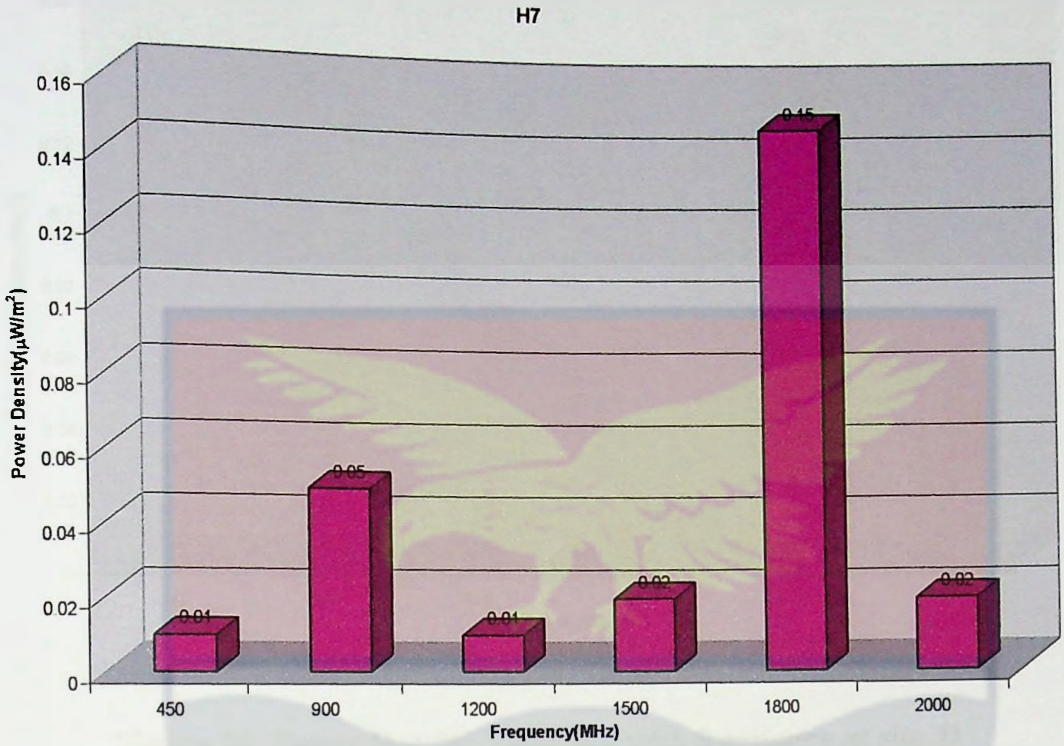

Figure 33: Power Density Variation with frequency at site H7

Plate 8: Typical Roof Top Tower at site H

Source: Field work (2007)

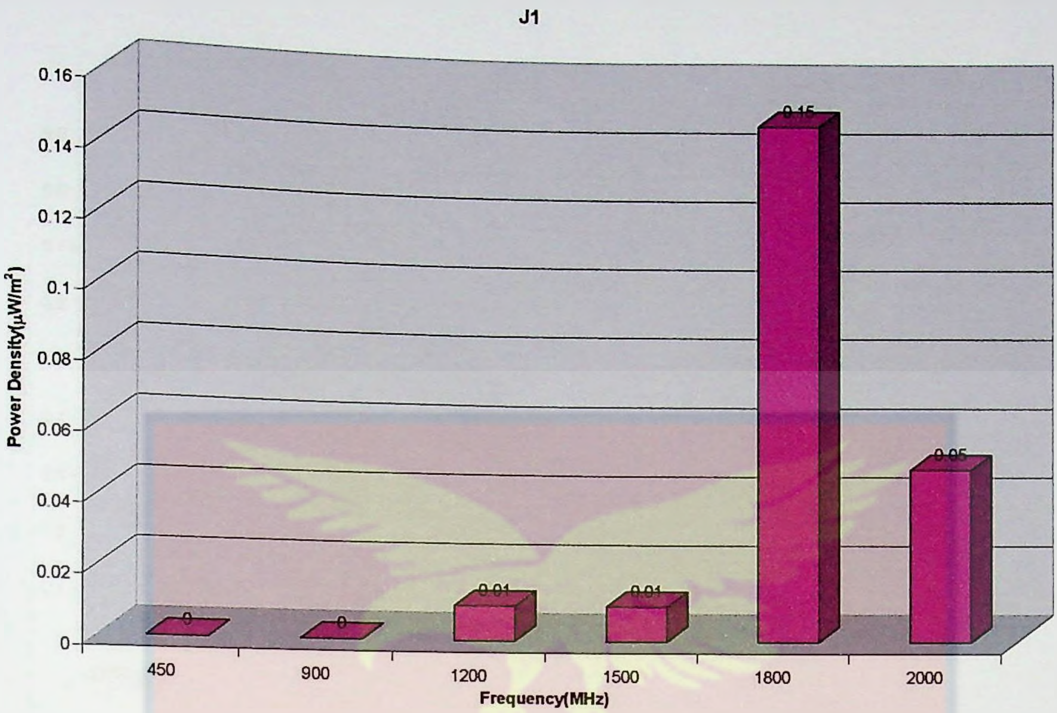

Figure 34: Power Density Variation with frequency at site J1

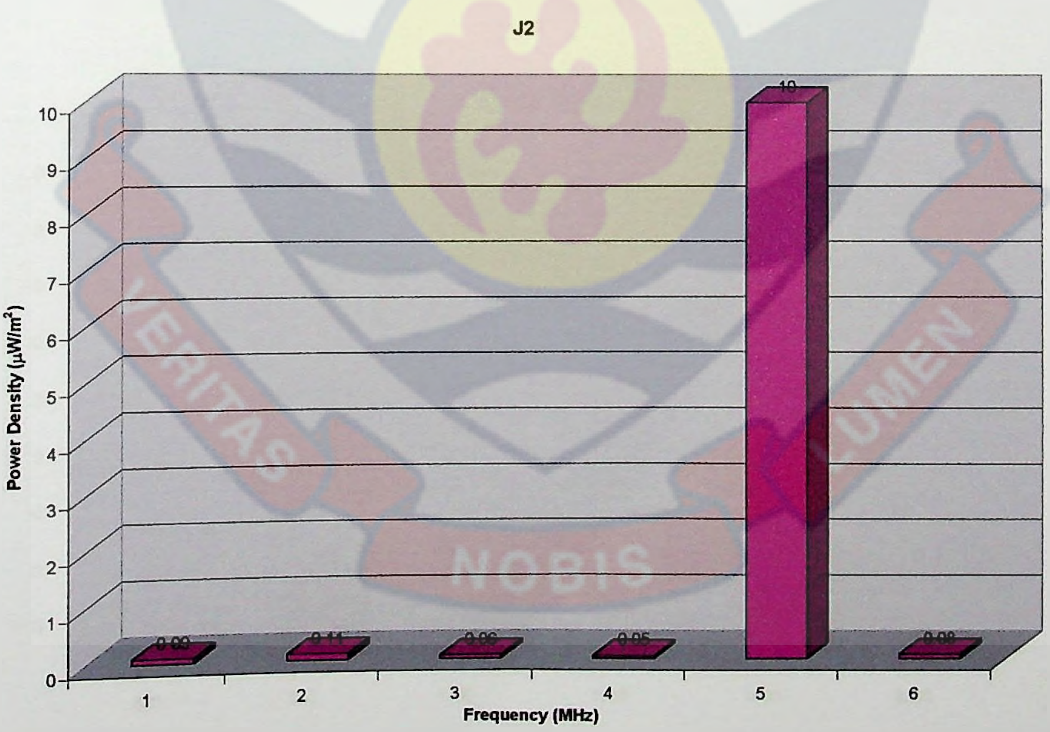

Figure 35: Power Density Variation with frequency at site J2

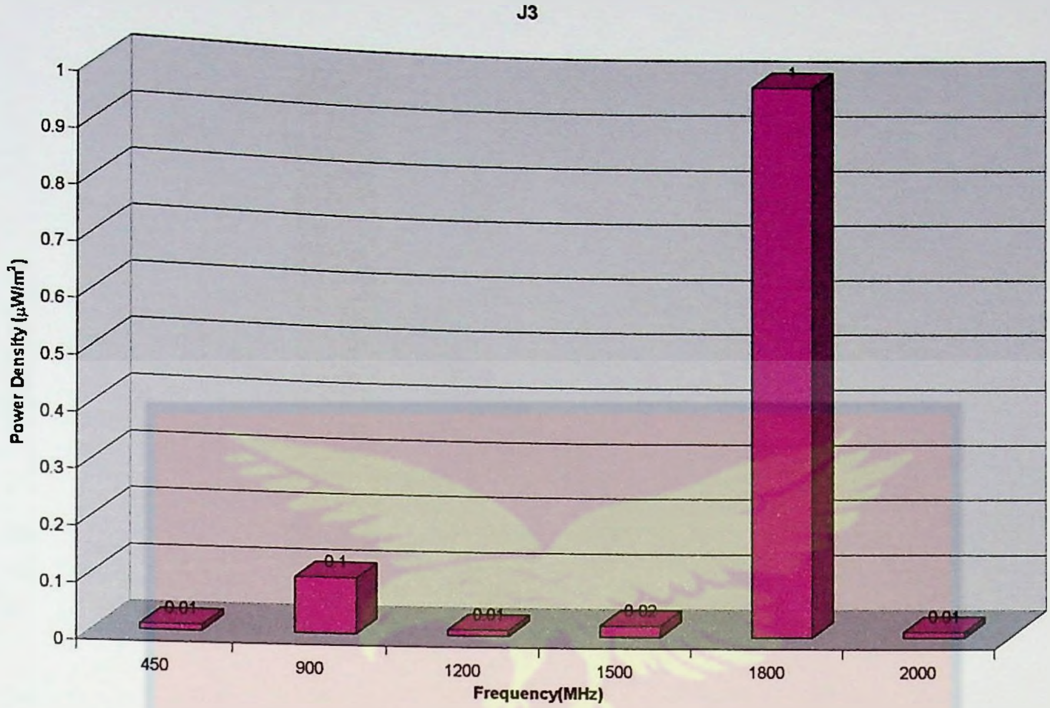

Figure 36: Power Density Variation with frequency at site J3

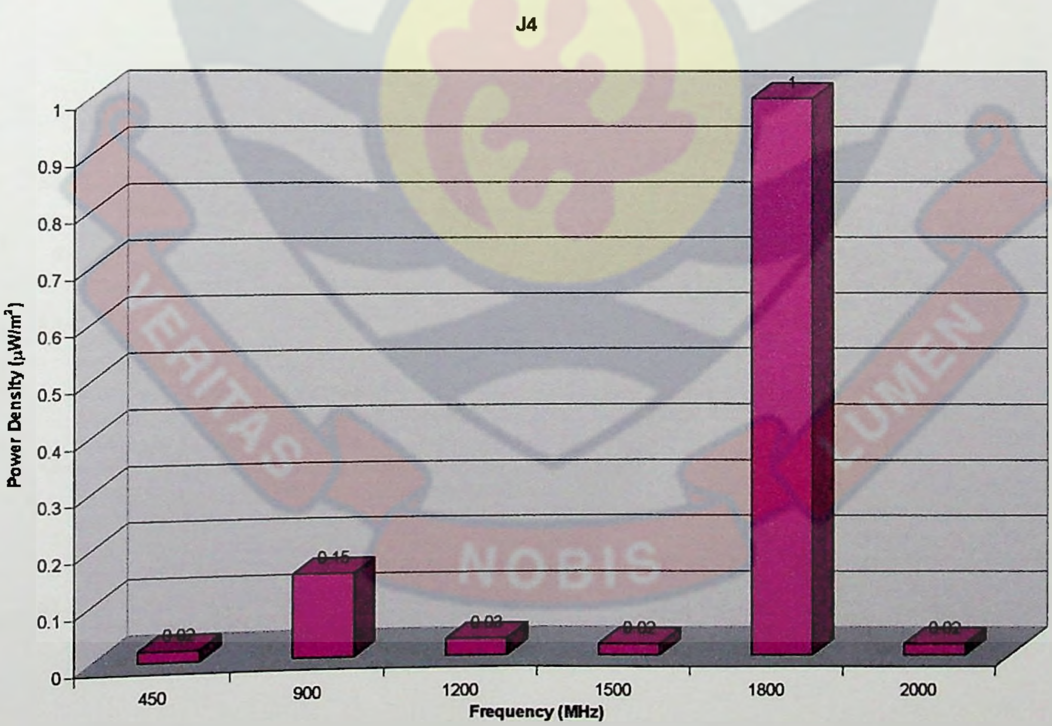

Figure 37: Power Density Variation with frequency at site J4

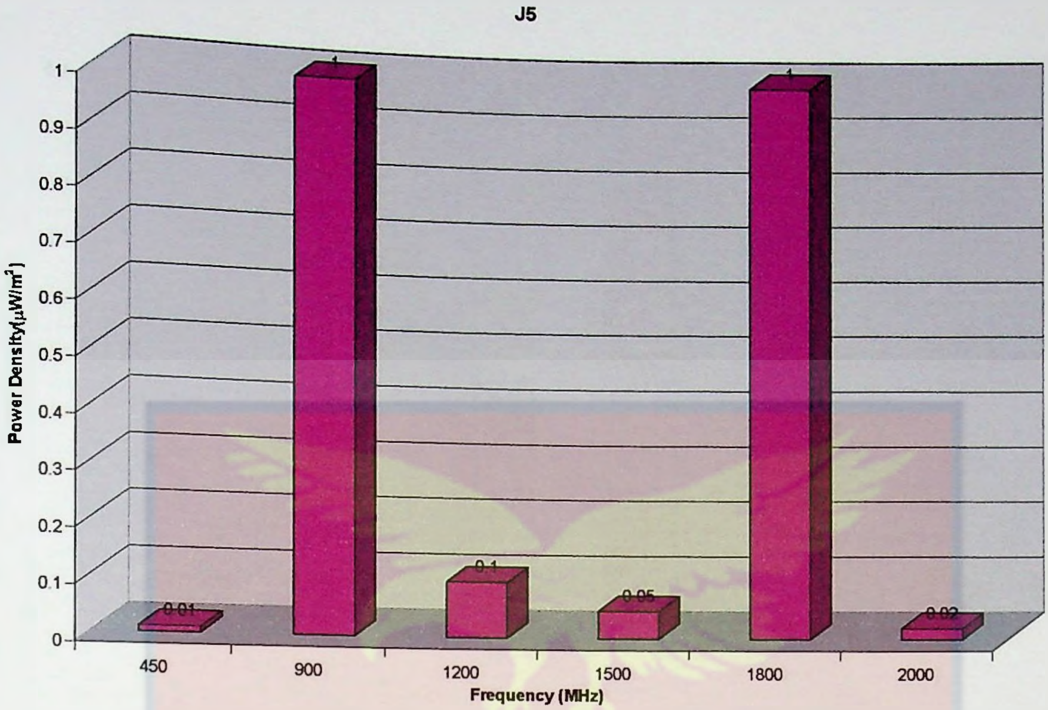

Figure 38: Power Density Variation with frequency at site J5

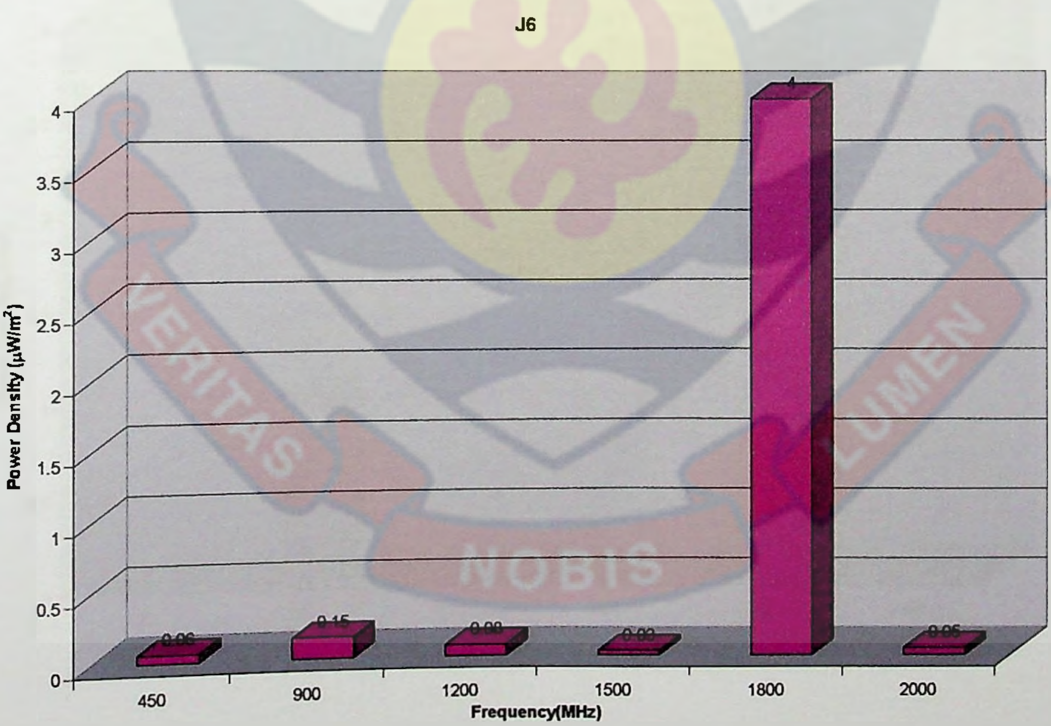

Figure 39: Power Density Variation with frequency at site J6

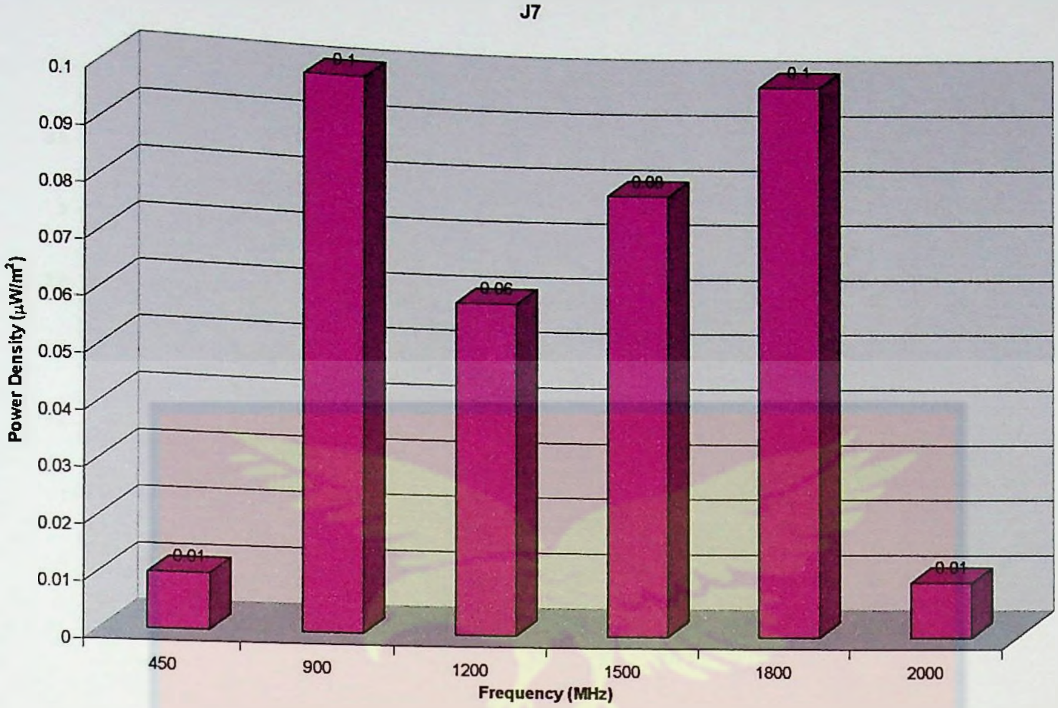

Figure 40: Power Density Variation with frequency at site J7

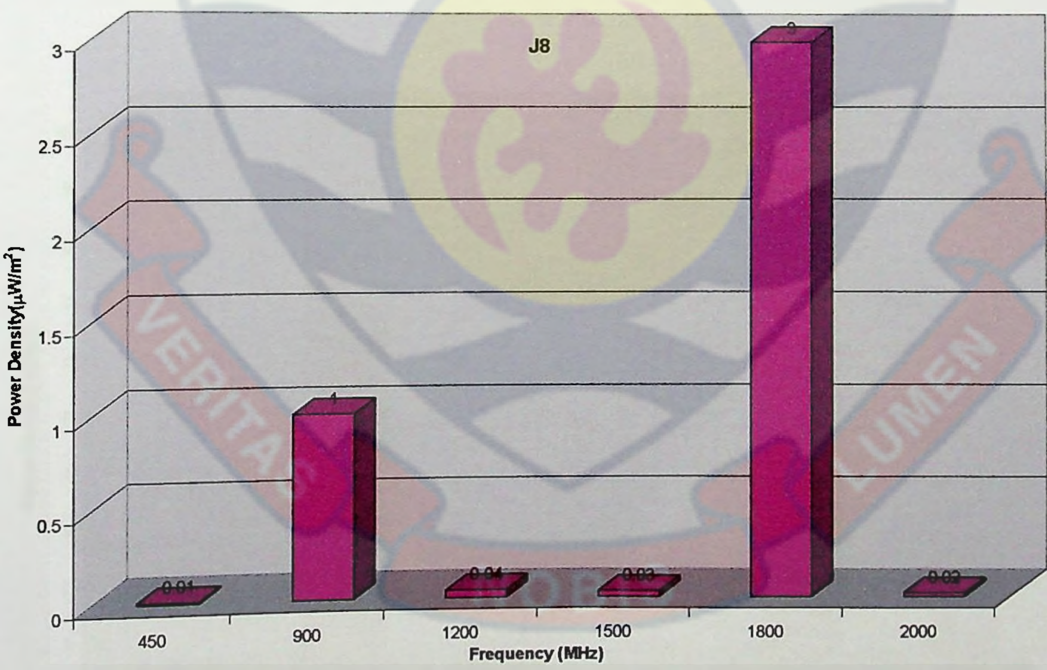

Figure 41: Power Density Variation with frequency at site J8

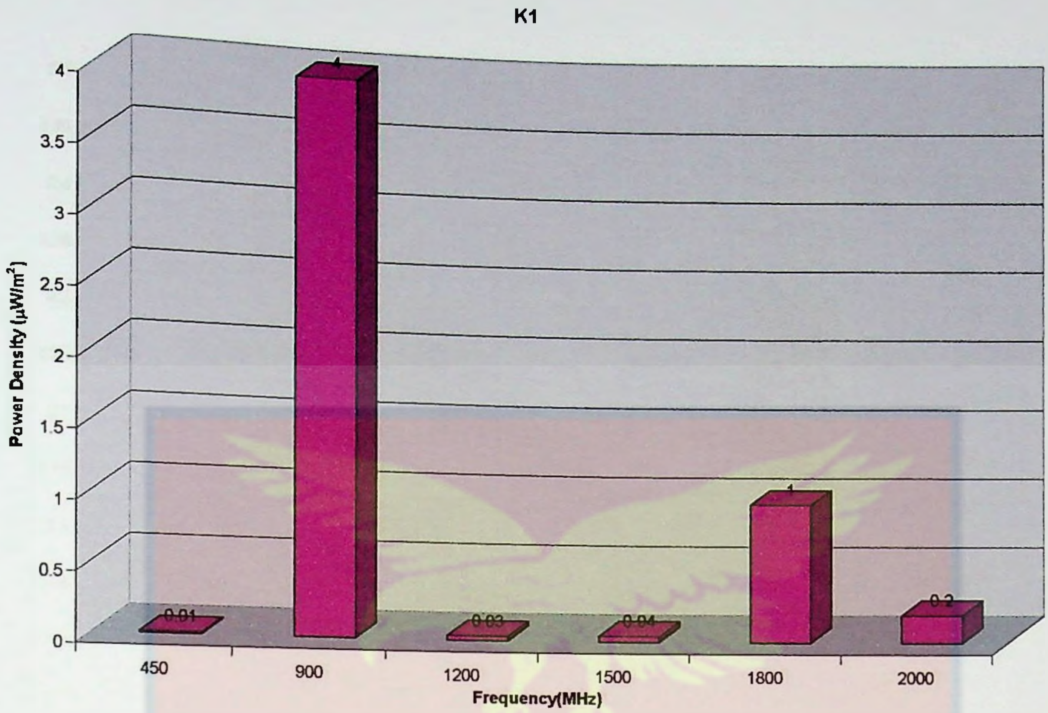

Figure 42: Power Density Variation with frequency at site K1

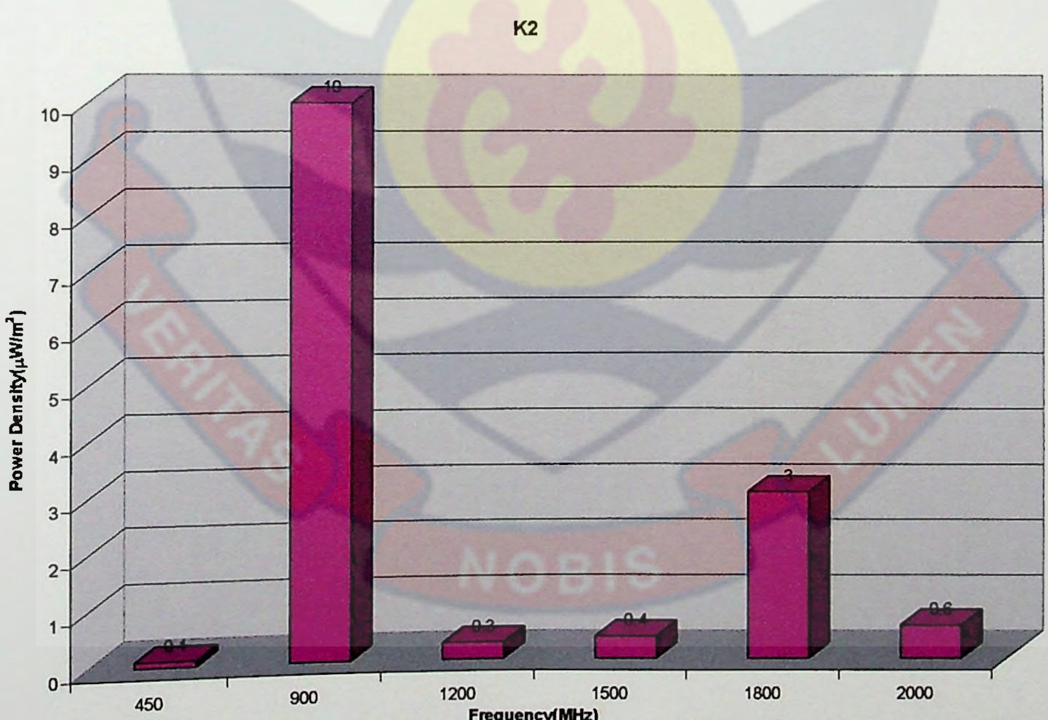

Figure 43: Power Density Variation with frequency at site K2

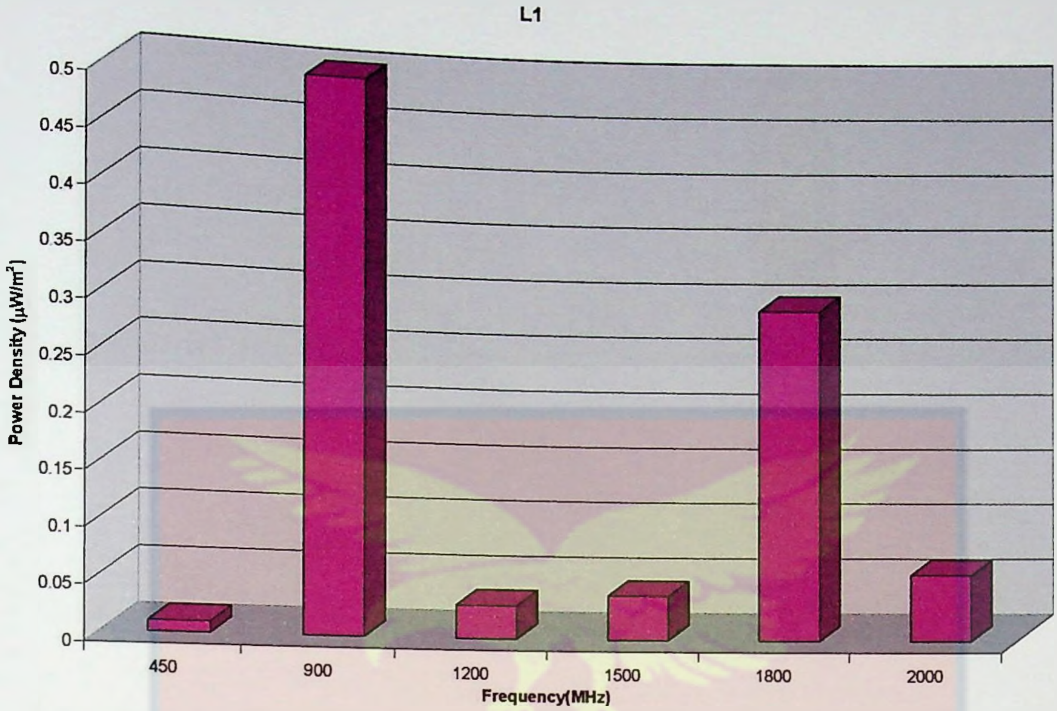

Figure 44: Power Density Variation with frequency at site L1

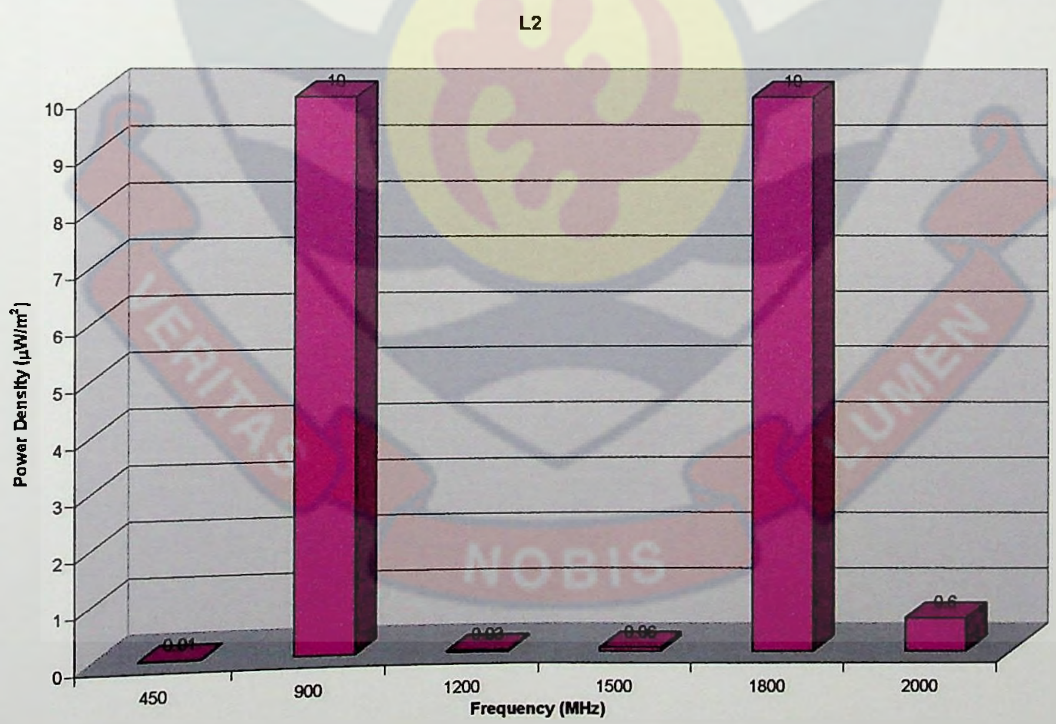

Figure 45: Power Density Variation with frequency at site L2

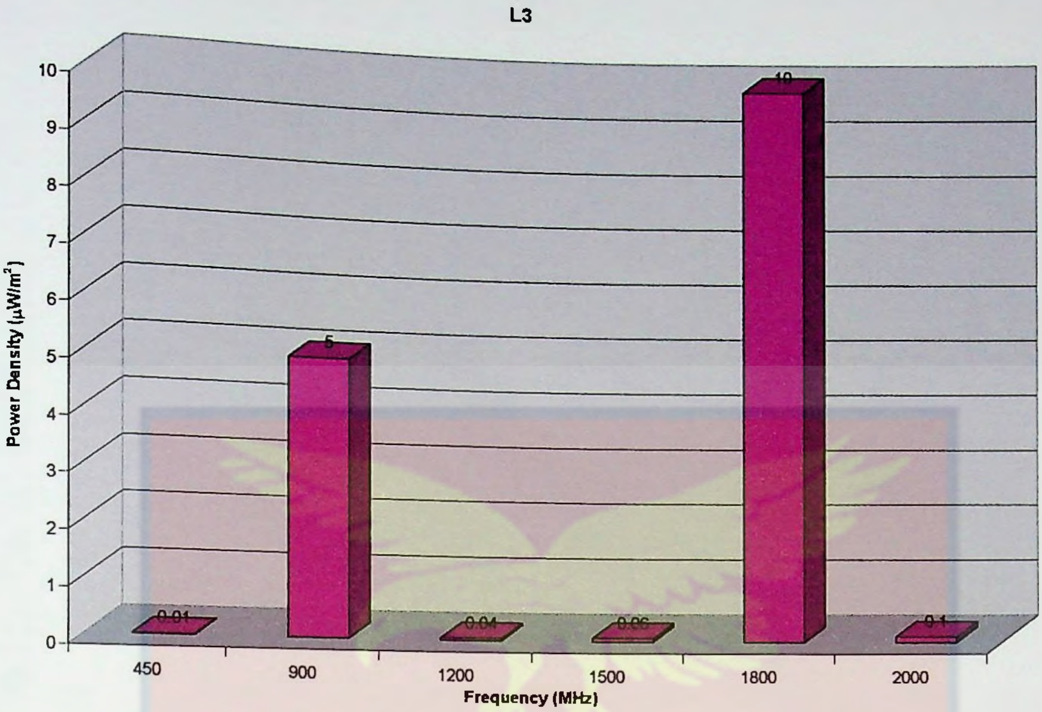

Figure 46: Power Density Variation with frequency at site L3

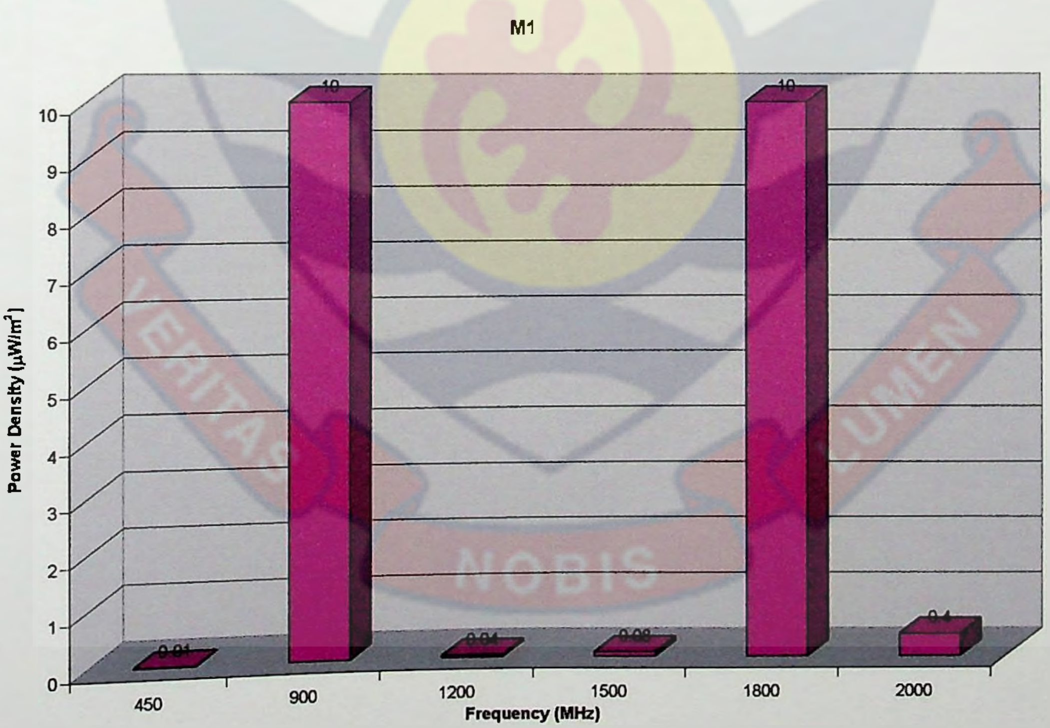

Figure 47: Power Density Variation with frequency at site M1

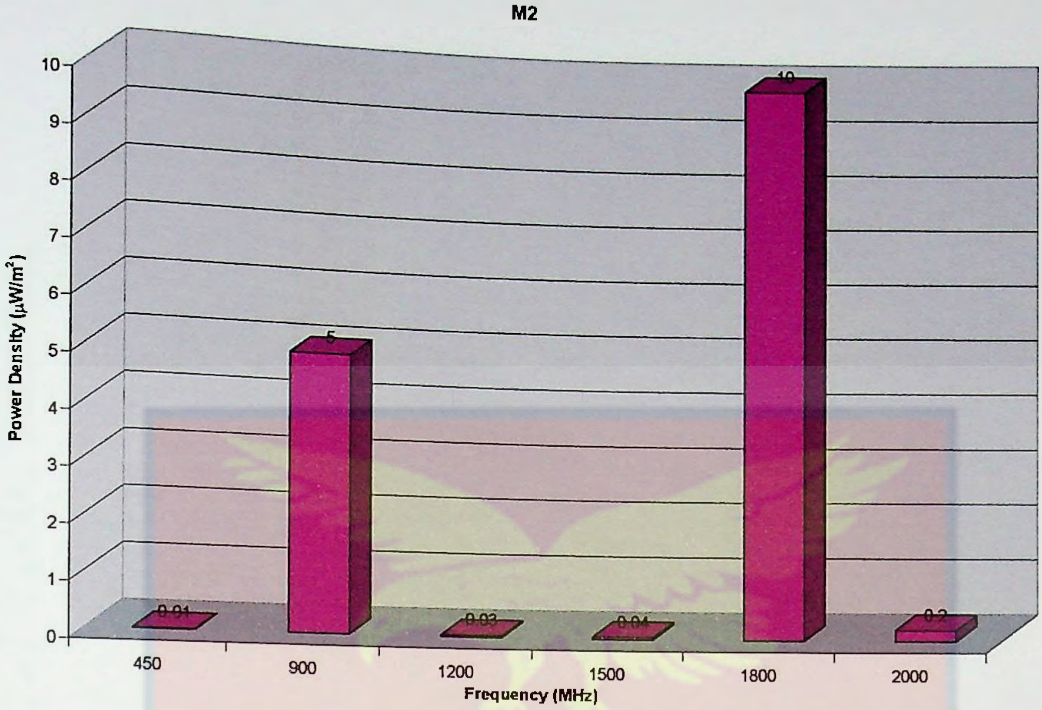

Figure 48: Power Density Variation with frequency at site M2

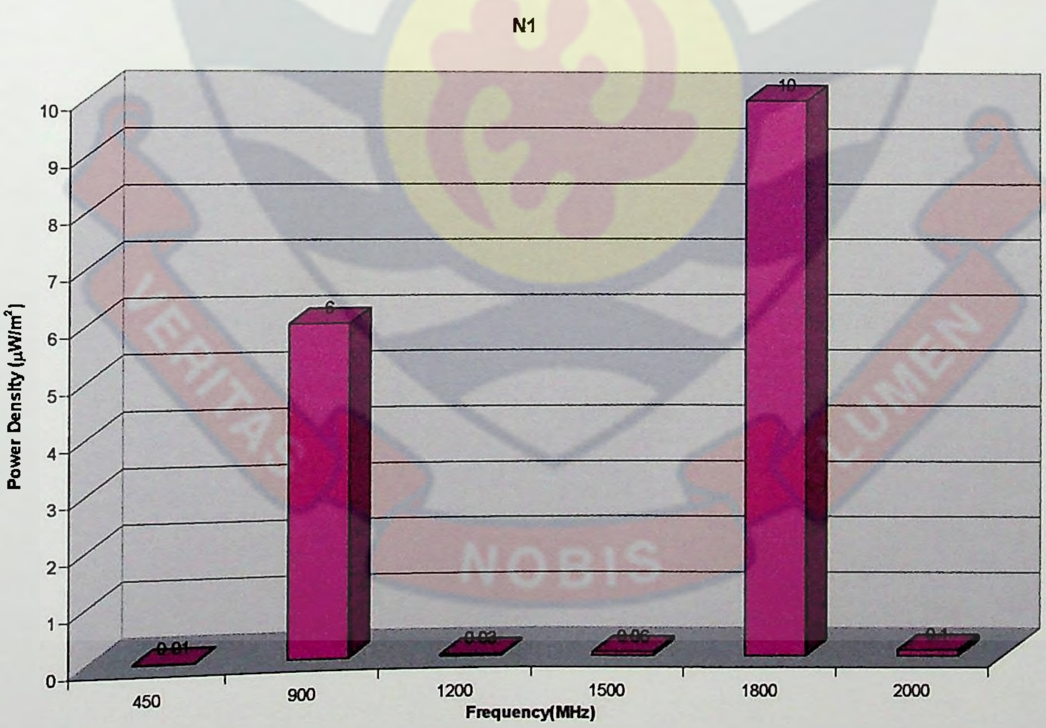

Figure 49: Power Density Variation with frequency at site N1

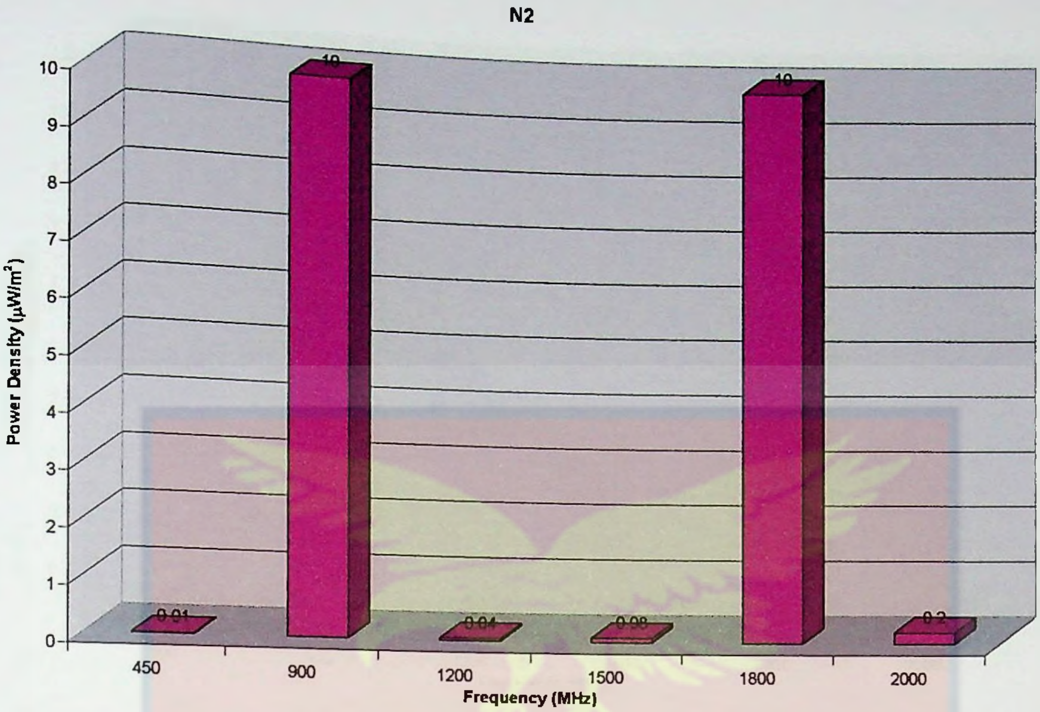

Figure 50: Power Density Variation with frequency at site N2

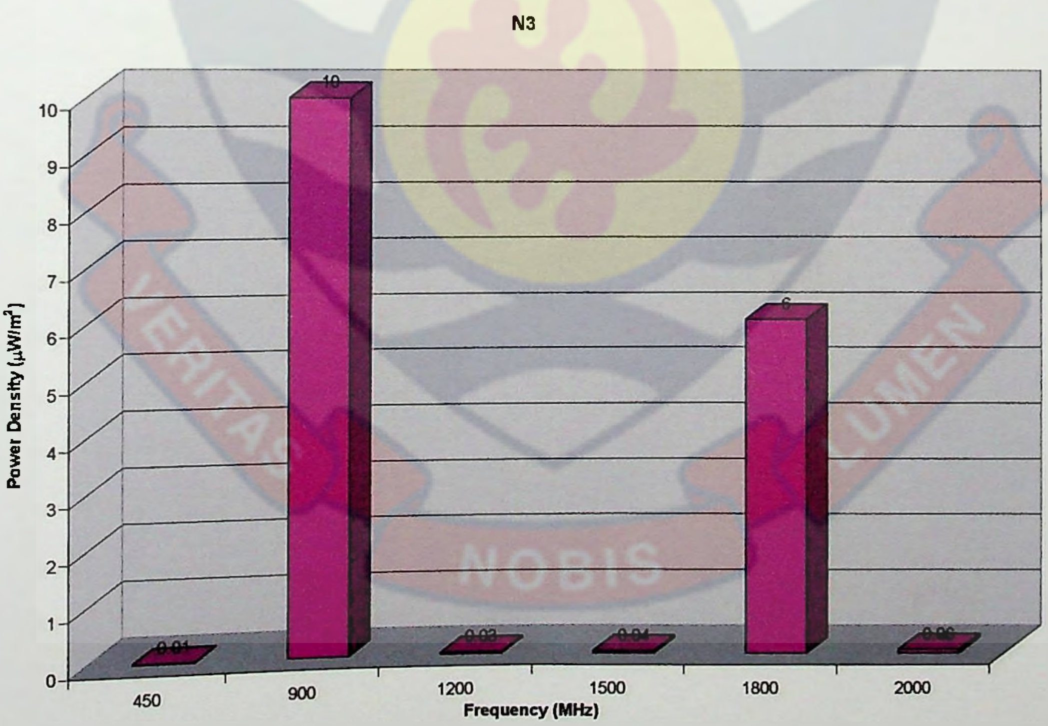

Figure 51: Power Density Variation with frequency at site N3

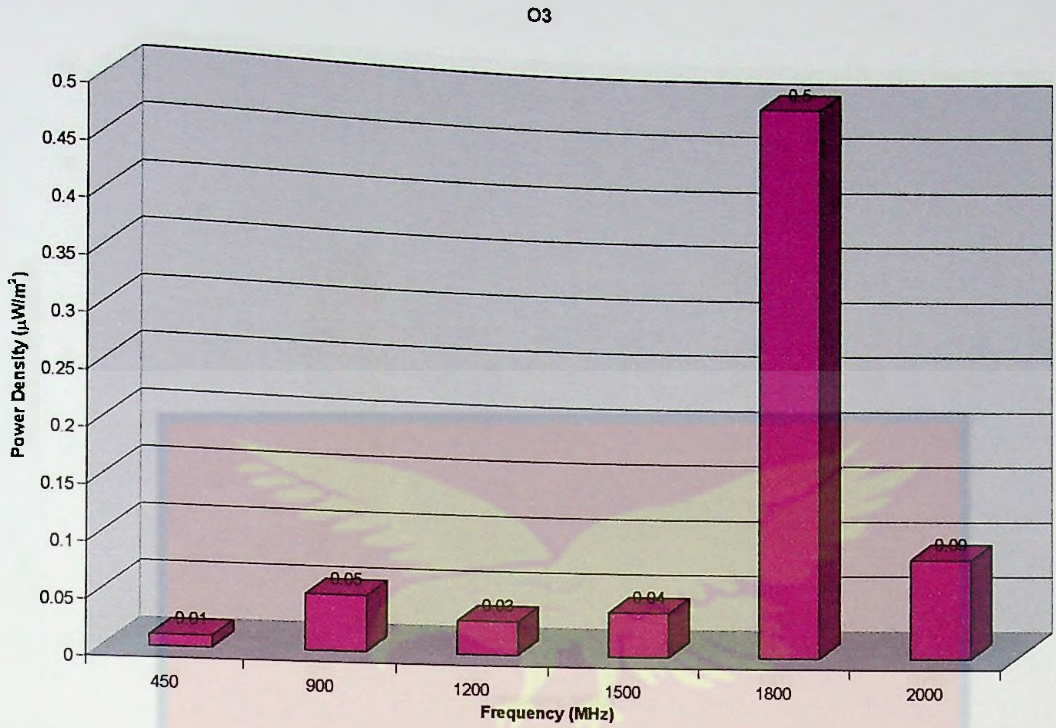

Figure 54: Power Density Variation with frequency at site O3

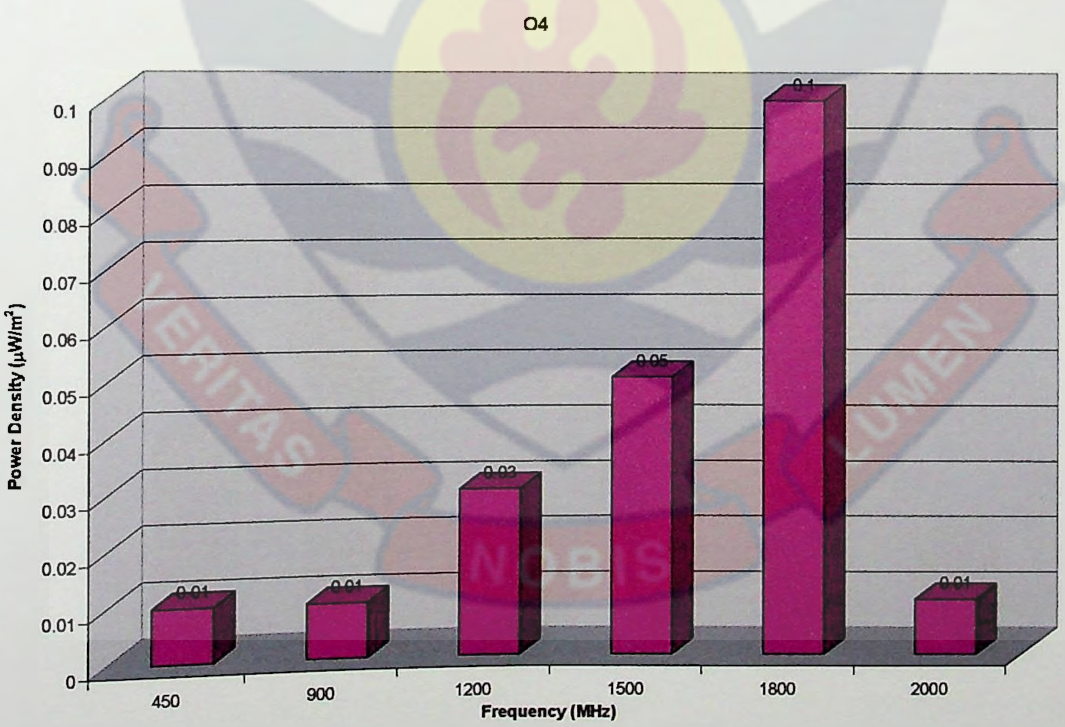

Figure 55: Power Density Variation with frequency at site O4

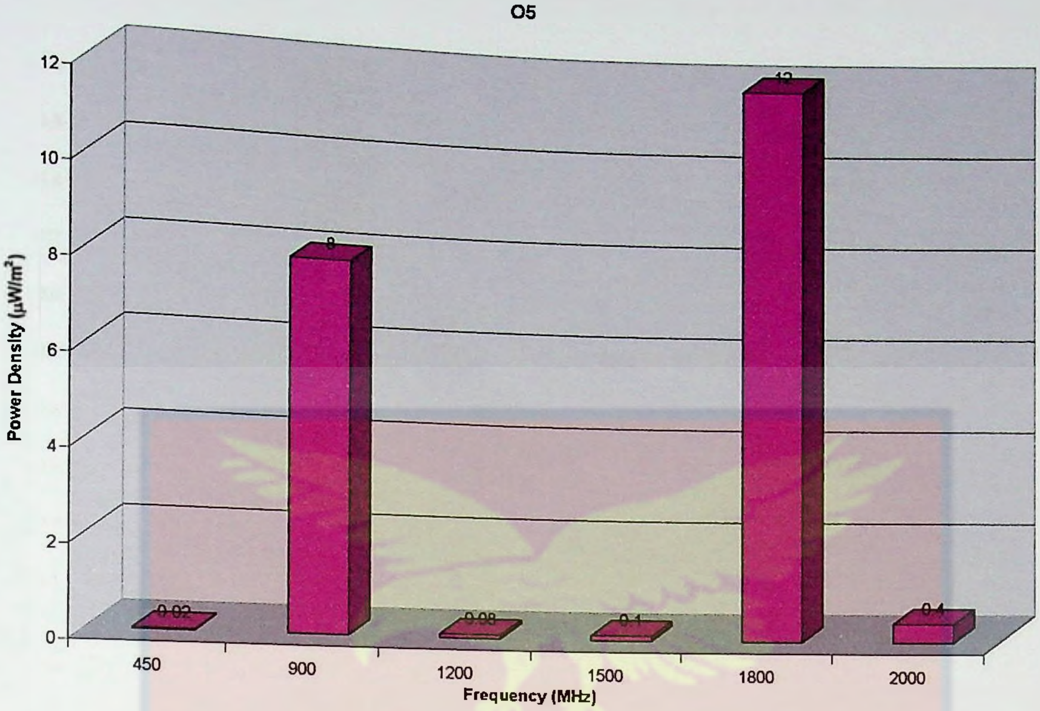

Figure 56: Power Density Variation with frequency at site O5

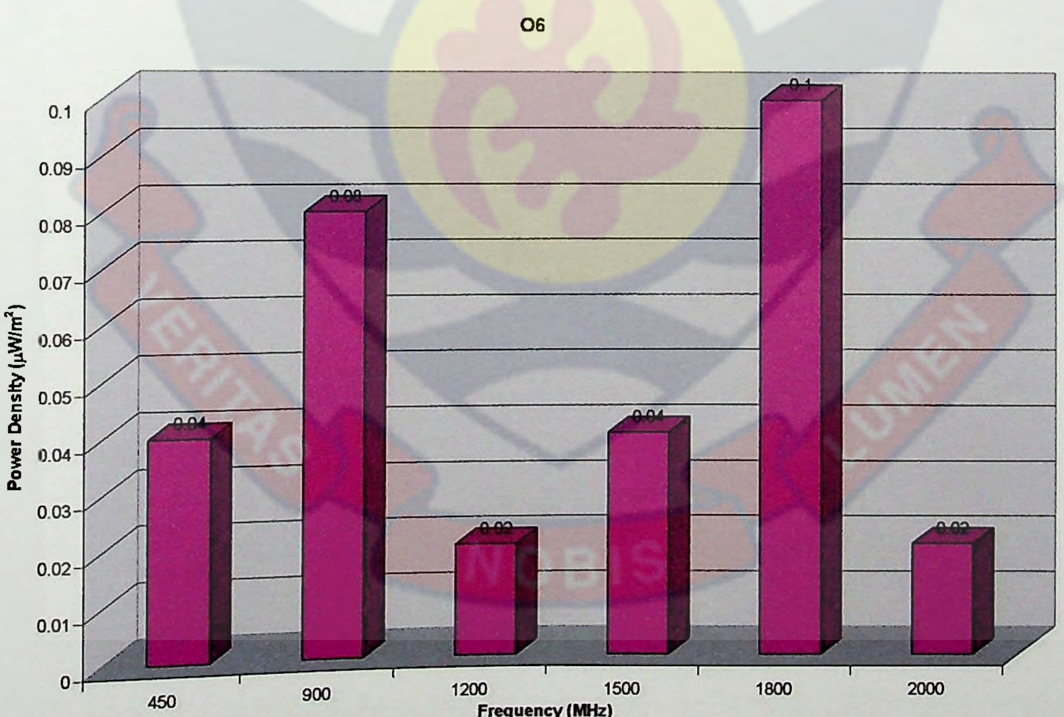

Figure 57: Power Density Variation with frequency at site O6

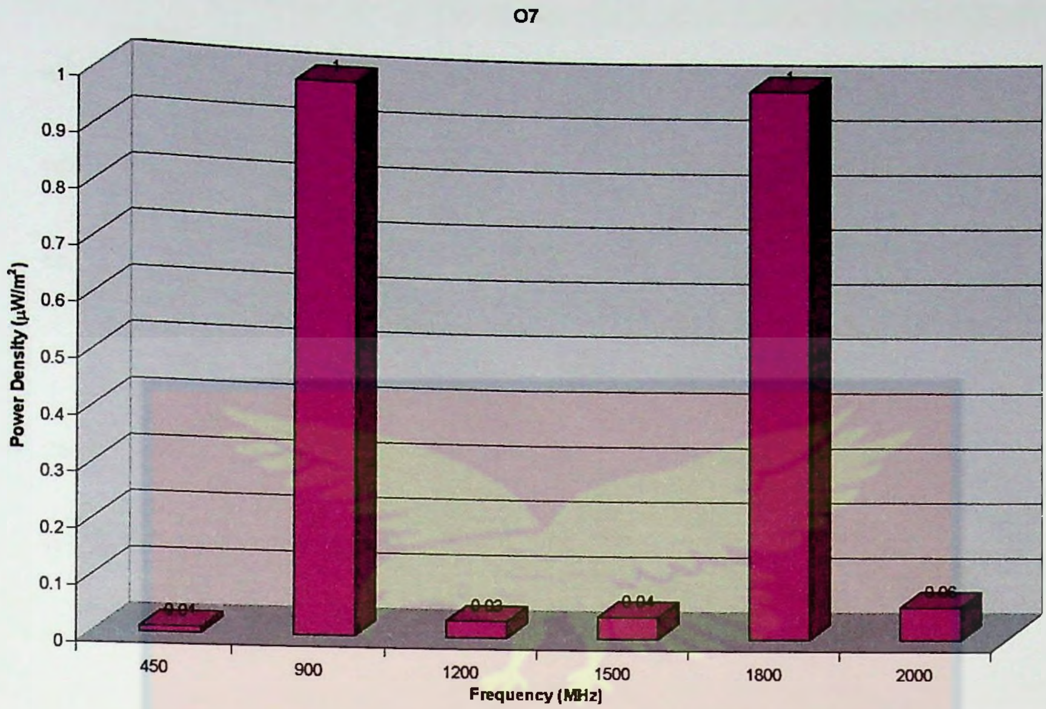

Figure 58: Power Density Variation with frequency at site O7

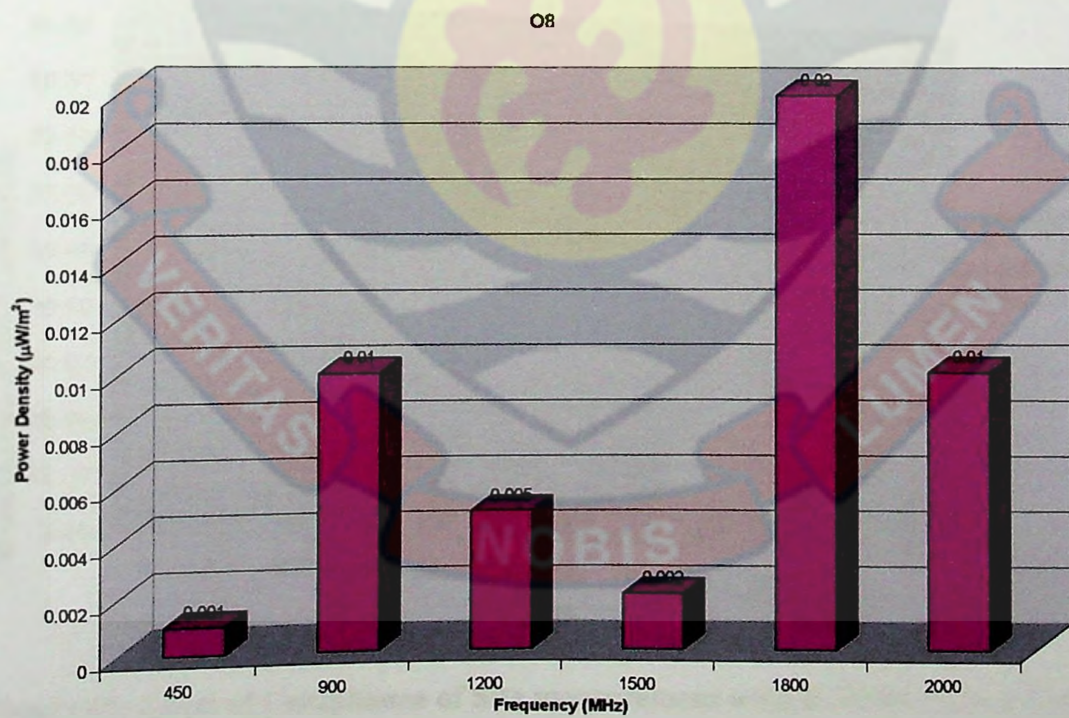

Figure 59: Power Density Variation with frequency at site O8

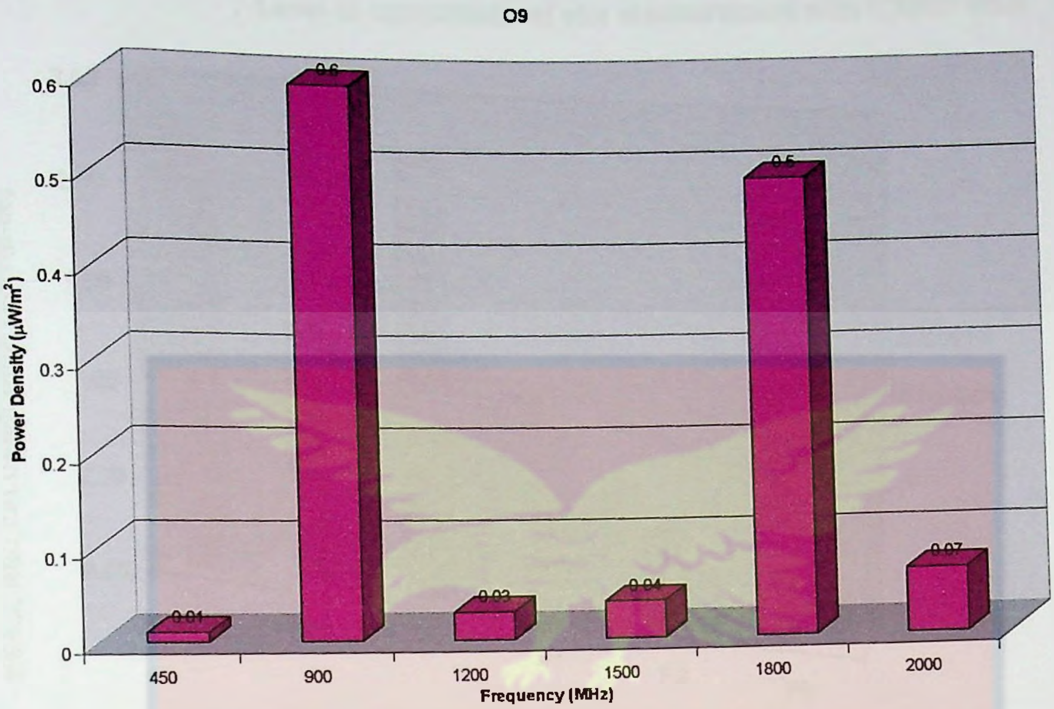

Figure 60: Power Density Variation with frequency at site O9

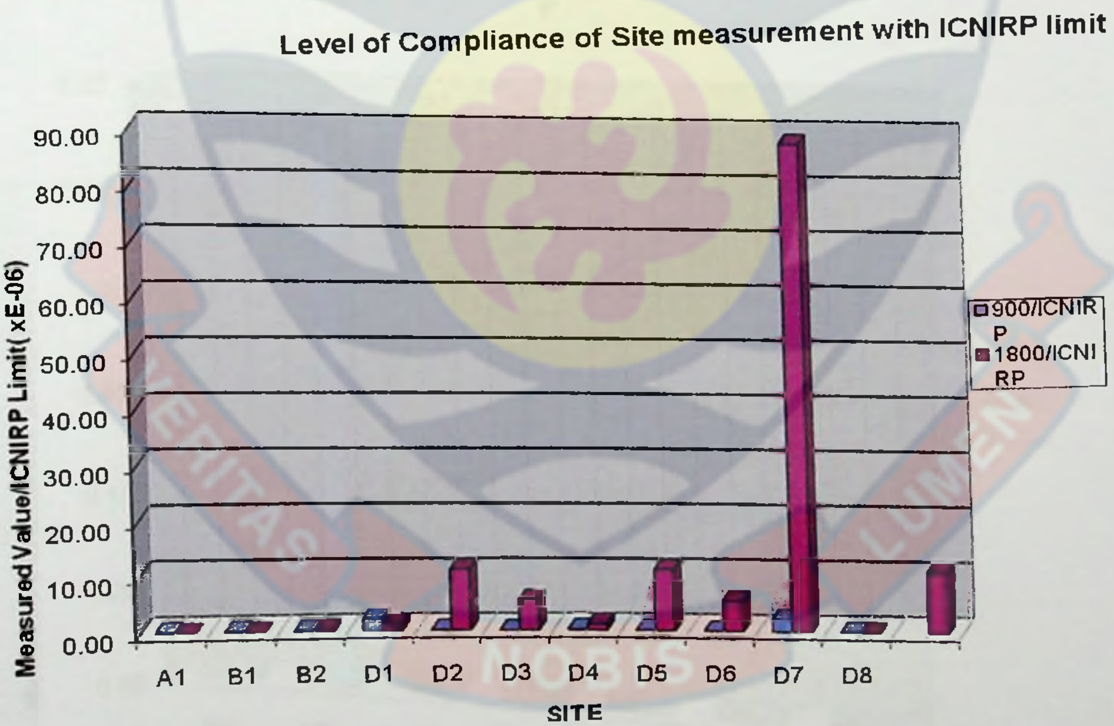

Figure 61: Level of Compliance of Site measurement with ICNIRP limit at sites A-D

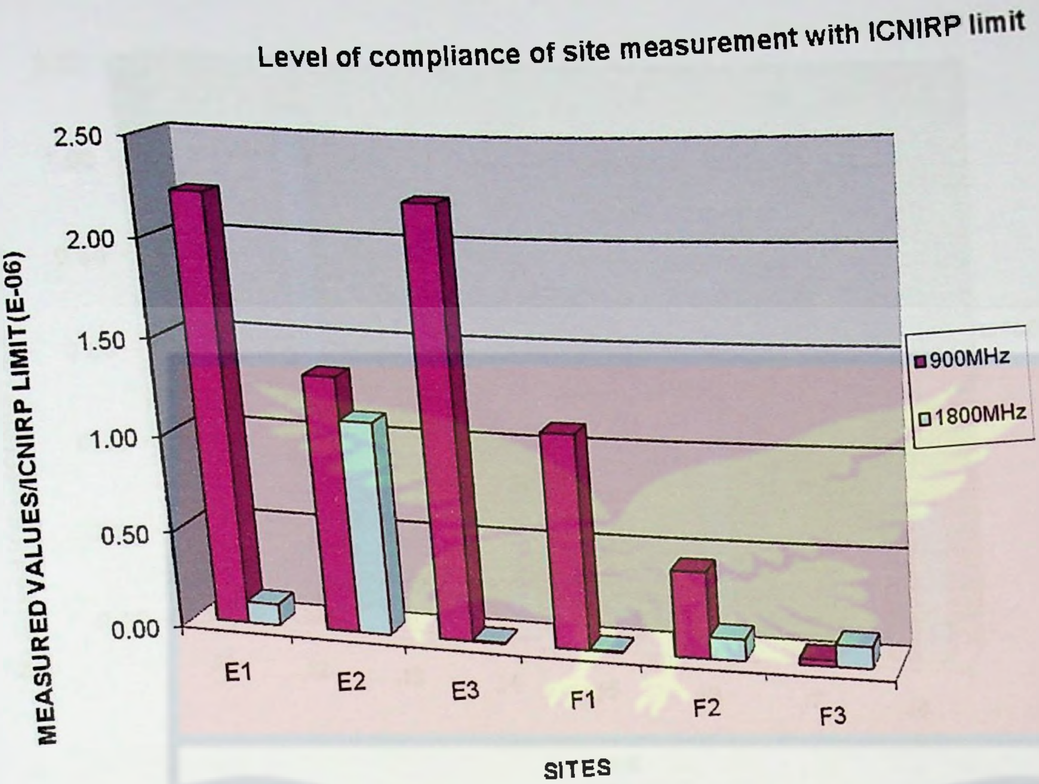

Figure 62: Level of compliance of site measurement with ICNIRP limit at site E-F

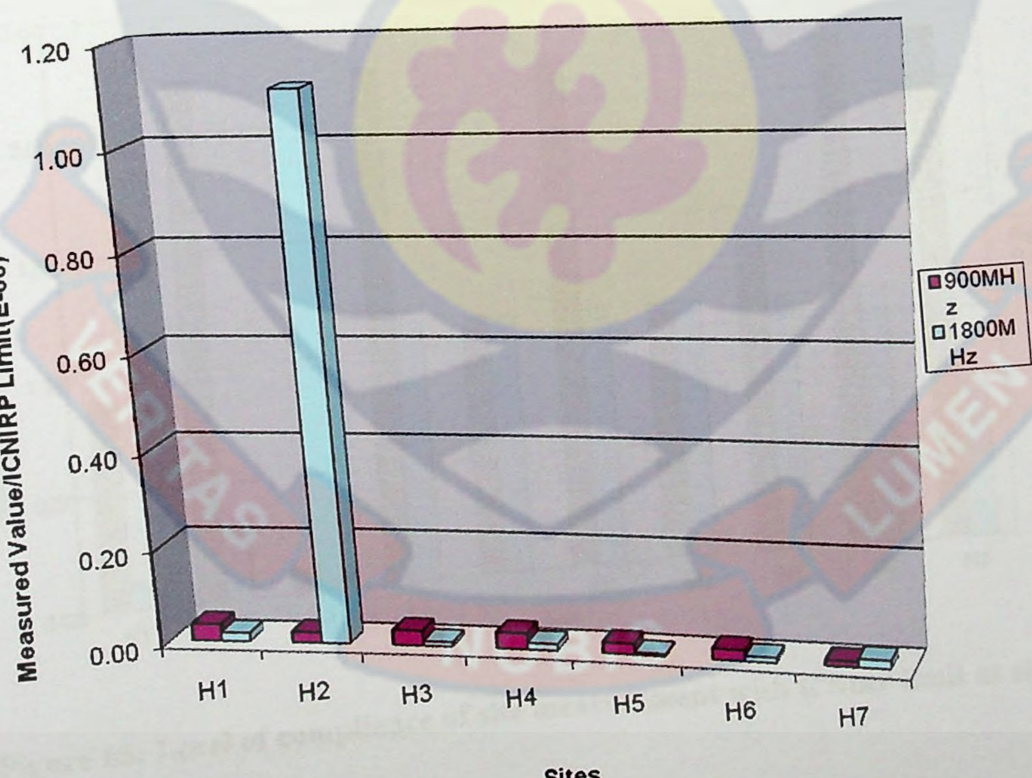

Figure 63: Level of compliance of site measurement with ICNIRP limit at site H

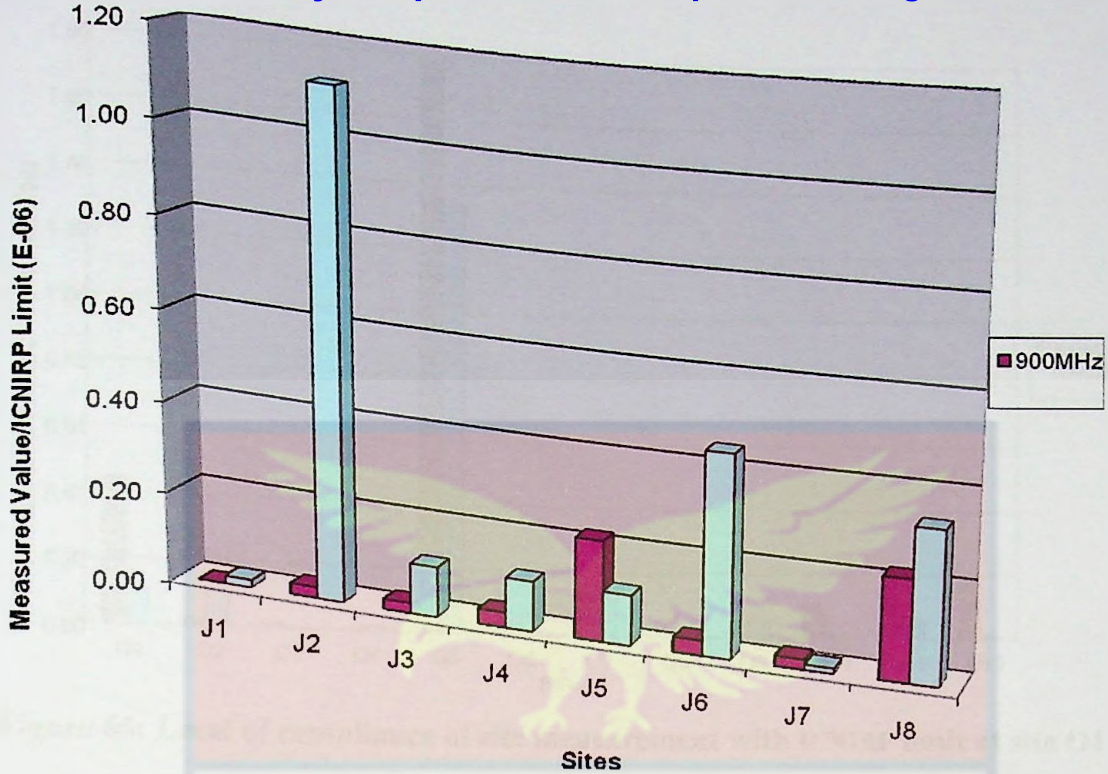

Figure 64: Level of compliance of site measurement with ICNIRP limit at site J

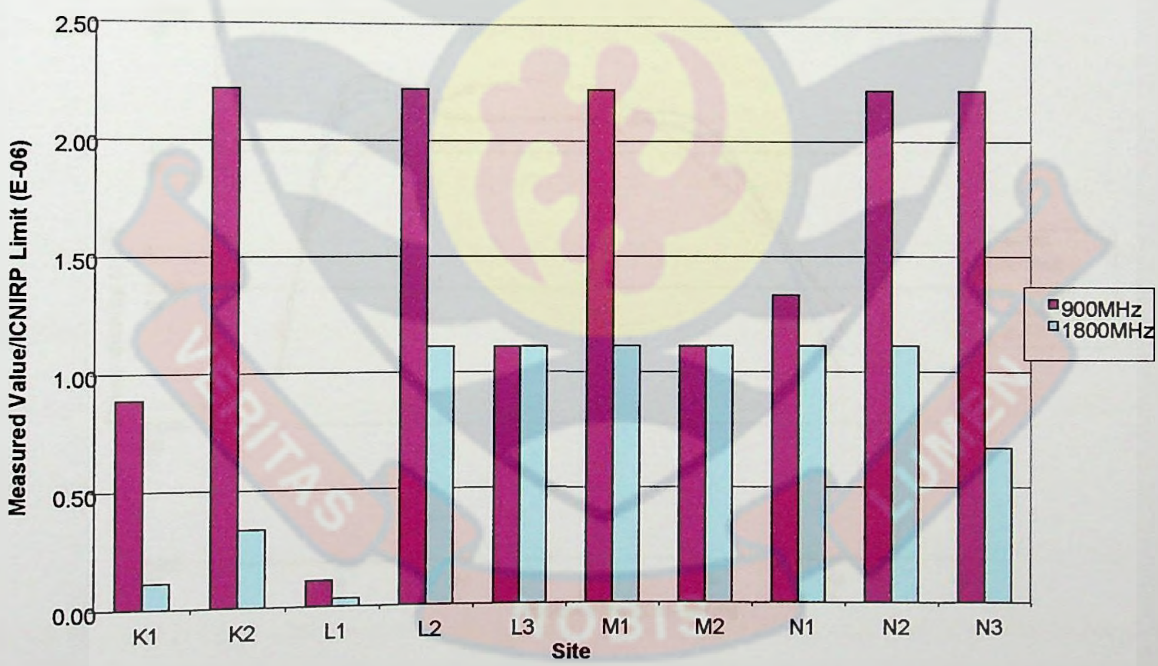

Figure 65: Level of compliance of site measurement with ICNIRP limit at site K-N

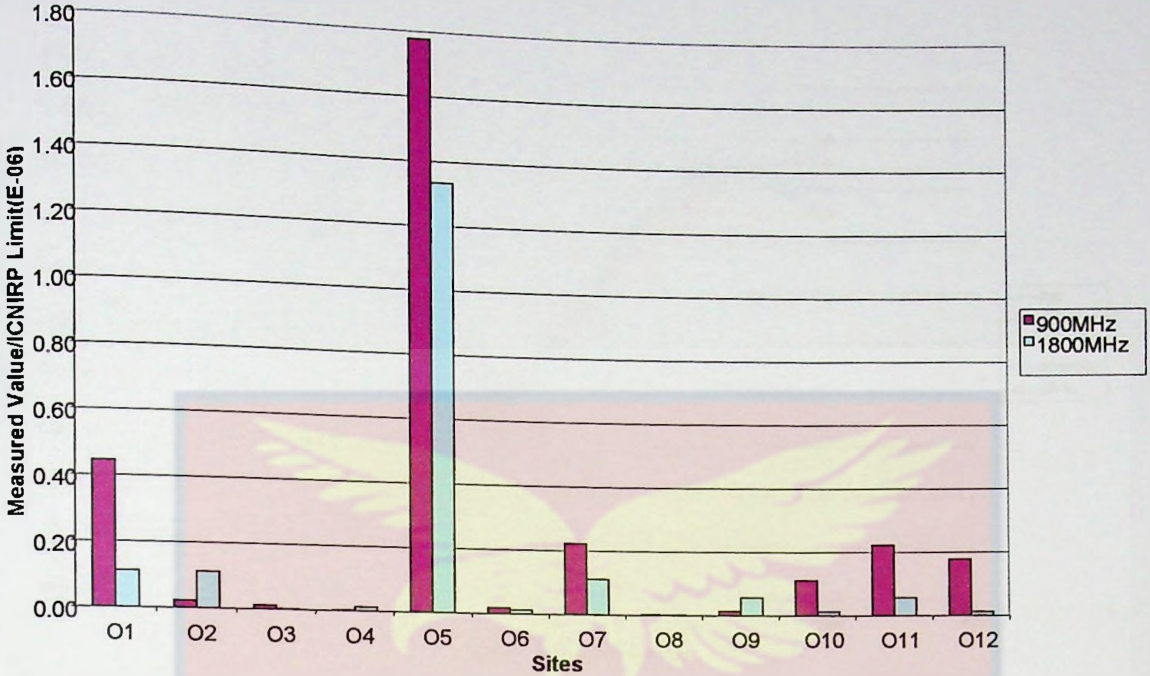

Figure 66: Level of compliance of site measurement with ICNIRP limit at site O1

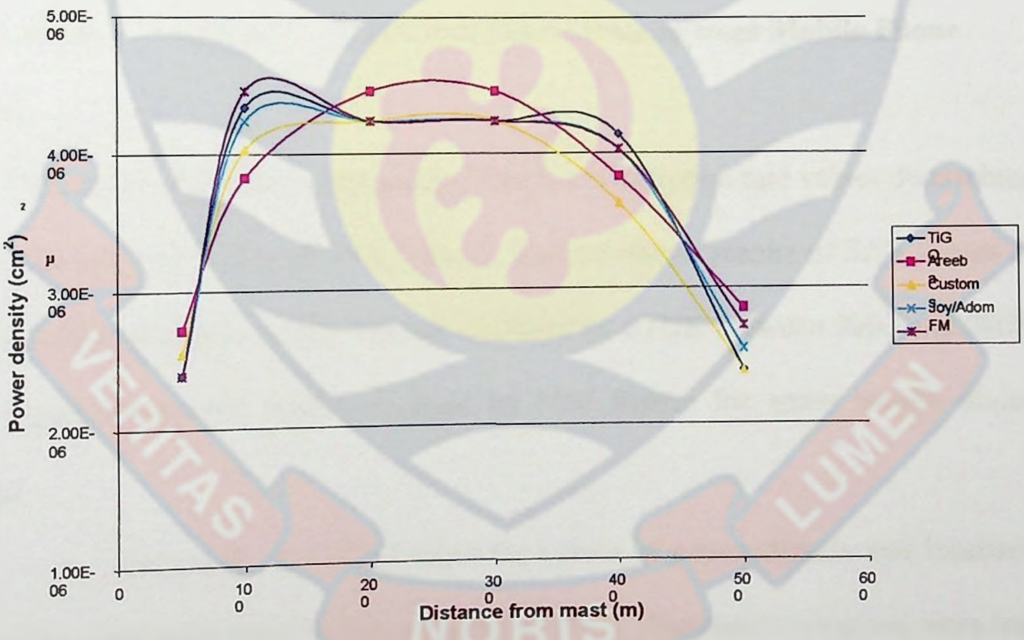

Figure 67: Chart showing the variation of power density variation with distances from various masts

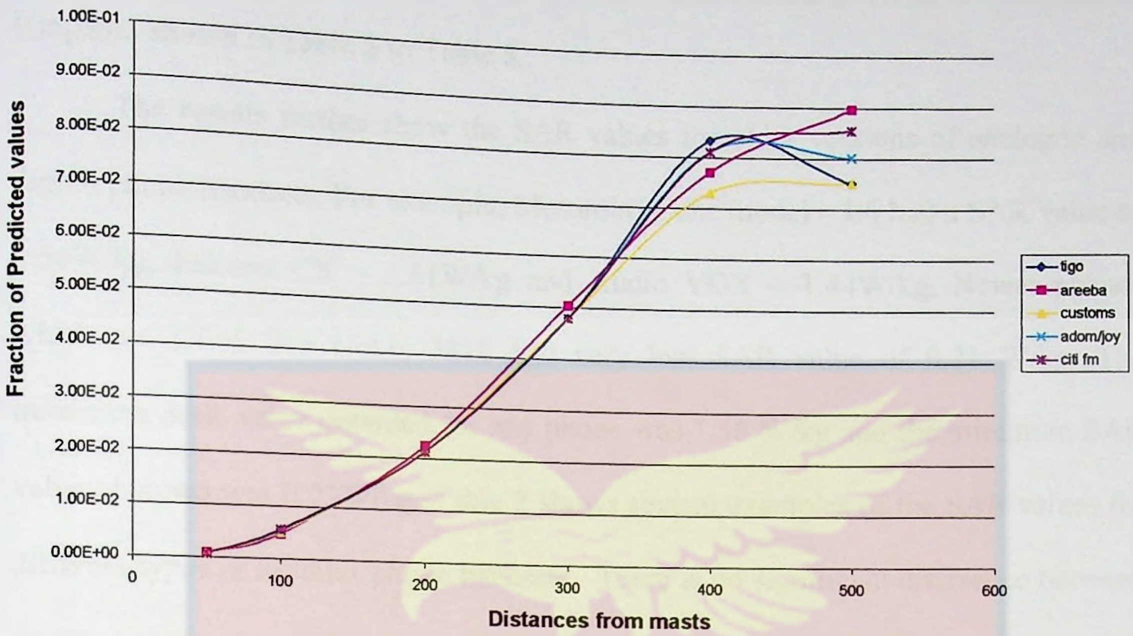

Figure 68: Chart showing the measured power density values as a fraction of the predicted values at different distances from mast

Results of Specific Absorption Rates and Power Density from Mobile Phone handsets

The results of Power Densities and Specific Absorption rate values determined in this work have been presented in Table 2. Table 3 shows results of SAR values of different model of mobile phone handset obtained by STUK between 2003 and 2009. Table 4 also shows the results obtained by Neil Kuster for some mobile phone handsets.

The results in Table 2 show the values of power density and localised SAR for the commonly used mobile phones in Ghana. The results obtained were less than the standard limits set by the Federal Communication Commission (FCC) of the USA, International Commission on Non-Ionising Radiation Protection (ICNIRP), the American National Standards Institute/Institute of Electrical and Electronic Engineers

(ANSI/IEEE) and National Radiological Protection Board (NRPB) of the United Kingdom shown in Table 5 to Table 8.

The results further show the SAR values for older versions of analogue and digital phone handsets. For example, Motorola phone model – L6 had a SAR value of 1.56W/kg, Ericson CX – 1.51W/kg and Audio VOX – 1.44W/kg. Newer phones which are GSM like Nokia 3810 had very low SAR value of 0.21 W/kg. The maximum SAR value obtained for any phone was 1.56 W/kg and the minimum SAR value obtained was 0.21W/kg. Table 2 shows several examples of the SAR values for different types of mobiles phone handsets. There is no significant difference between power density values of phones when receiving signals and when making calls.

The results obtained from this study were generally lower than those obtained by Kuster Niels of Swiss Federal Institute as shown in Table 4. Kuster measured the SAR values for 16 models of mobile phones some of which were used in this study. His results appear to be higher than current study.

The results obtained by STUK (2009), the average SAR for all the phones tested was 0.73W/kg. The maximum and minimum SAR values obtained were 1.41W/kg and 0.27W/kg respectively. The results shows that all the phones tested had SAR values below the recommended 1.6W/kg. The results from STUK is comparable to the results obtained from this work

The FCC (1997) sets a maximum power density of 4mW/cm^2 for devices that operate in the frequency band as cellular phones. But the International Standard says that power density measurements can only be used for devices that operate at a distance greater than 20 centimetres from the human body. Devices operating within 20 centimetres of the human body, such as cellular phones, must use the SAR of 1.6

W/kg. The SAR values for the phones used in this study show that all the phones were in compliance with these limits.

Table 2: Power Density and SAR values for different types of mobile phones used in Ghana

No.	Manufacturer	Model	Power Density (mW/cm^2) X 10^{-1}	SAR (W/kg) [1]
1.	Audiovox	PCX – 1000XL	0.93±0.05	0.98±0.05
2.	Audiovox	CDM 4000	0.93±0.05	0.98±0.05
3.	Audiovox	HGP2000E	0.71±0.04	0.74±0.04
4.	Audiovox	9000	1.23±0.06	1.30±0.07
5.	Audiovox	3300	1.38±0.07	1.44±0.07
6.	Ericsson	SH888	0.41±0.02	0.42±0.02
7.	Ericsson	S828	0.73±0.04	0.76±0.04
8.	Ericsson	A1018s	0.84±0.04	0.87±0.04
9.	Ericsson	SH888	0.86±0.04	0.89±0.05
10.	Ericsson	GF788	0.87±0.04	0.91±0.05
11.	Ericsson	GH688	0.90±0.05	0.95±0.05
12.	Ericsson	DH-668	1.25±0.06	1.31±0.07
13.	Ericsson	A228D	1.29±0.06	1.35±0.07
14.	Ericsson	T18	1.33±0.07	1.40±0.07
15.	Ericsson	R280	1.34±0.07	1.41±0.07
16.	Ericsson	LX-588	1.44±0.07	1.51±0.08
17.	Motorola	GSM1900	0.95±0.05	1.00±0.05
18.	Motorola	Star Tac 130	0.09±0.01	0.12±0.01
19.	Motorola	Star Tac	0.28±0.01	0.30±0.02
20.	Motorola	I1000plus	0.33±0.02	0.35±0.02
21.	Motorola	CD 930	0.67±0.03	0.70±0.04
22.	Motorola	D160	0.77±0.04	0.80±0.04
23.	Motorola	cd 930	0.90±0.05	0.94±0.05
24.	Motorola	cd 920	1.11±0.06	1.16±0.06
25.	Motorola	Star tac (TDMA)	1.19±0.06	1.25±0.06
26.	Motorola	1500	1.19±0.06	1.25±0.06
27.	Motorola	Sc-3160	1.45±0.07	1.52±0.07
28.	Motorola	L6	1.50±0.08	1.56±0.08
29.	Motorola	C330	1.09±0.05	1.14±0.06
30.	Motorola	C115	1.06±0.05	1.11±0.06
31.	Motorola	C115	1.06±0.05	1.11±0.05
32.	Nokia	1611	1.01±0.06	1.06±0.05
33.	Nokia	8810	0.20±0.05	0.21±0.05
34.	Nokia	6150	0.66±0.05	0.69±0.05
35.	Nokia	8110i	0.70±0.05	0.72±0.05
36.	Nokia	6110	0.82±0.05	0.86±0.05
37.	Nokia	3210	1.09±0.05	1.14±0.05

Table 3: Tested mobile phones at STUK, STUK (2009) Cont'd

Nokia 1600	0.62	0.82
Nokia 2100	0.55	0.55
Nokia 2600	0.53	0.80
Nokia 2610	0.58	0.56
Nokia 2650	0.48	0.54
Nokia 3100	0.63	0.76
Nokia 3200	0.55	0.56
Nokia 3220	0.59	0.78
Nokia 3310	0.91	0.96
Nokia 3510	0.58	0.66
Nokia 5100	0.47	0.48
Nokia 5140	0.86	0.77
Nokia 6021	0.37	0.72
Nokia 6030	0.62	0.70
Nokia 6060	0.65	0.77
Nokia 6085	0.71	1.15
Nokia 6100	0.61	0.60
Nokia 6103	0.48	0.75
Nokia 6151	0.84	1.02
Nokia 6220	0.65	0.66
Nokia 6270	0.28	0.74
Nokia 6610	0.97	0.63
Nokia 6630	0.69	0.83
Nokia 6810	0.87	0.82
Nokia 6822	0.71	0.67
Nokia 9500 Communicator	0.27	0.49
Nokia E51	0,97	1,47
Nokia E65	0,53	0,87
Nokia E71	0,53	1,33
Nokia N70	1.01	0.95
Nokia N73	0.85	1.12
Nokia N-Gage QD	0.48	0.57
Samsung		
Samsung SGH-A800	0.88	0.96
Samsung SGH-B100	0,77	0,91
Samsung SGH-C100	0.74	0.60
Samsung SGH-E330	1.17	0.90
Samsung SGH-L760	0.78	0.554
Samsung SGH-X100	0.54	0.76
Samsung SGH-X200	0.87	0.74
Samsung SGH-X300	0.39	0.58
Samsung SGH-X450	1.13	0.98
Samsung SGH-X460	0.79	0.846
Samsung SGH-X510	0.77	0.781
Samsung SGH-X680	0.59	0.801

Table 3: Tested mobile phones at STUK, STUK (2009) Cont'd

Samsung SGH-X820	1.15	0.639
Samsung SGH-Z540	0.38	0.54
Siemens		
Siemens A55	0.45	0.56
Siemens A60	0.75	0.67
Siemens A65	0.28	0.49
Siemens A70	0.35	0.52
Siemens CF62	0.75	0.75
Siemens M55	0.80	0.64
Siemens MC60	0.60	0.67
Siemens ME45	1.12	0.98
SonyEricsson		
SonyEricsson J230i	0.70	0.98
SonyEricsson J300i	1.31	1.02
SonyEricsson K500i	0.53	0.53
SonyEricsson T230	0.50	0.74
SonyEricsson T310	0.53	0.61
SonyEricsson T630	0.85	0.88
SonyEricsson W300i	1.03	1.20
SonyEricsson W350i	1,41	1,46
SonyEricsson Z200	0.77	0.94
SonyEricsson Z300	0.90	0.75
SonyEricsson Z310i	0.43	0.7
Average	**0.73**	**0.80**
Maximum	**1.41**	**1.47**
Minimum	**0.27**	**0.30**

Source: STUK, 2009

Table 4: Power density and Localized Specific absorption rate values obtained by Kuster Niels commonly used mobile phones.

Manufacturer	Model	Power density W/kg
Motorola	Startac 130	0.10
Nokia	Nokia 8810	0.22
Siemens	C25	0.73
Ericson	SH 888	0.90
Audiovox	3300	1.45
Motorola	V3688	1.58
Panasonic	EBG 500	0.98
Samsung	SCH 6100	1.38
Nokia	6162	1.42
Nokia	7160	1.39
Ericsson	T18	1.40
Motorola	CD 930	0.70
Audiovox	9000	1.30
Ericsson	GH 688	1.33

Source: Swiss Consumer Association 2004

Temperature in Tissue – Equivalent Phantom

Figure 69 shows the results obtained experimentally in a PMMA tissue equivalent phantom.

The results obtained shows very small change in temperature over 10 minutes of exposure to RF radiation at 900MHz and 1800 MHz. From the chart, there was

0.14°C change over the initial 20°C for the 1800MHz. At the 900 MHz the temperature change was 0.13°C. These measured temperatures were comparable with values obtained using other type of phantoms which tends to mimic the human tissue. The results obtained using the PMMA phantom in this work was slightly lower than obtained by other investigators using other types of phantoms. The results however are consistent with other results obtained by other investigator. For instance, Bernardi & Cavagnaro et al, (2000), measured temperatures in head of mobile phone users using different antennas. Their results shows temperature changes of between 0.1°C and 0.19°C for different power densities and SAR values.

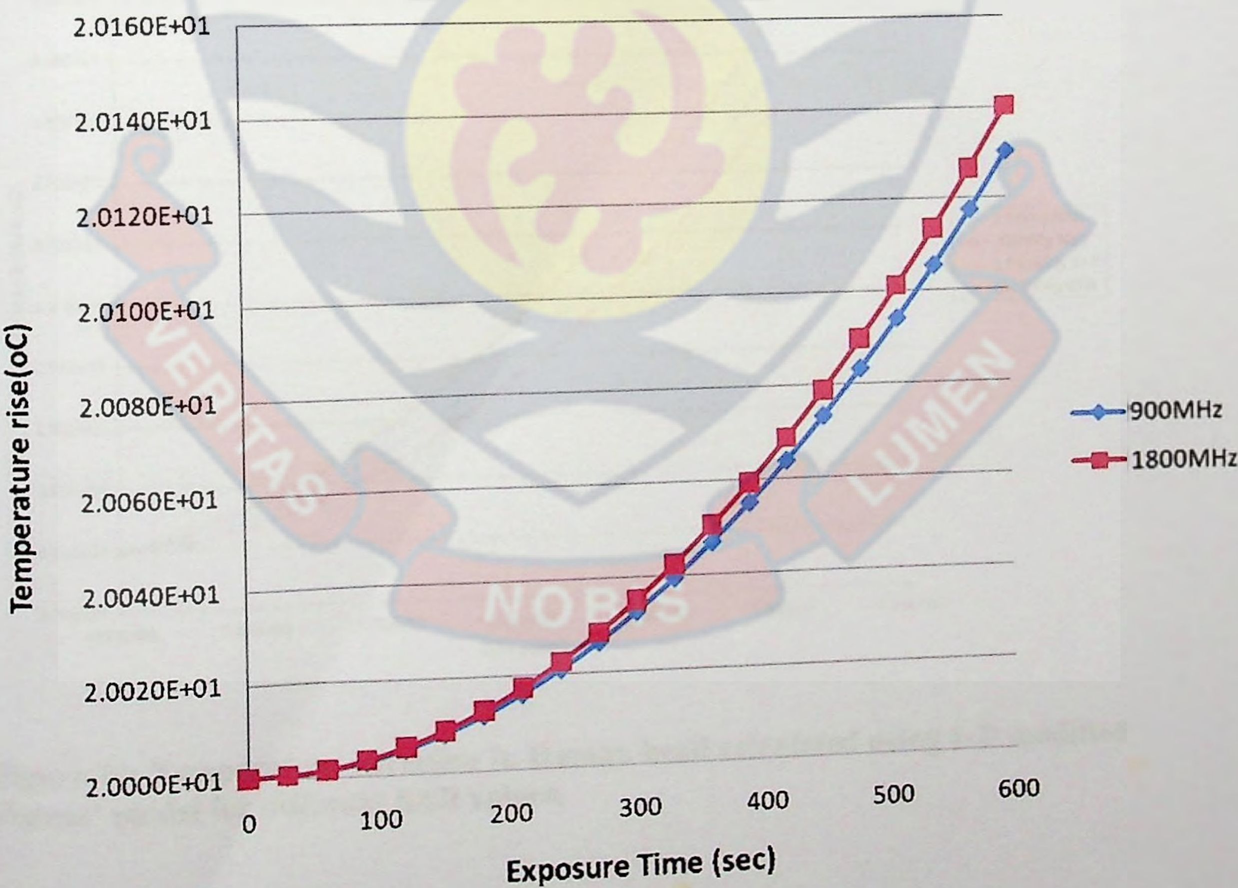

Figure 69: Temperature variation with time with tissue equivalent phantom

Calculated Values of Temperature Variation in Human Tissue

Figure 70 shows the results of temperature changes in the human head using 1-D solution of the modified Pennes bioheat model.

The head is a very important organ when determining the safety of radiofrequency radiation emitted from mobile phones. These results were obtained from calculation using the 1-D solution for the standard Bioheat equation described on pages 83 to 86 of this work and show the average SAR values calculated for the different mobile phone handsets used in Ghana. Average SAR values of 0.42W/kg, 0.98W/kg, 1.7W/kg, and 1.94W/kg resulted in temperature rise of 0.14°C, 0.15°C, 0.17°C and 0.18°C respectively after 10minutes of exposure.

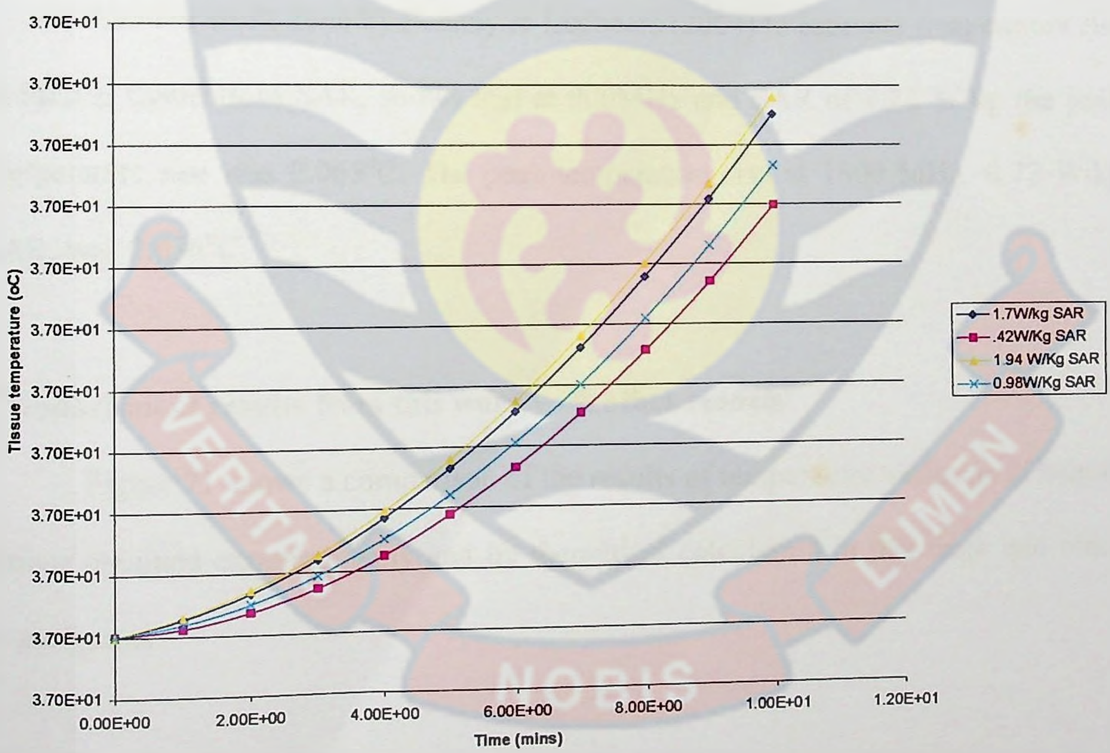

Figure 70: Temperature variation in Human head calculated using 1-D modified Pennes' model for different SAR values.

These results show that the SAR distribution within the tissue is related to the temperature distribution. The results compare favourably with results obtained by Flyckt et al. (2007). They calculated the SAR and temperature rise in a high-resolution vascularized model of the human eye and orbit when exposed to a dipole antenna at 900, 1500 and 1800 MHz. The temperature rises from their work were, 0.22°C, 0.27°C and 0.25°C respectively.

Similar work done by Van Leeuween et al. (1999), predicted maximum temperature of 0.11°C. This result was obtained for a 917MHz dipole antenna with time-averaged power output of 0.25W and SAR of 1.6W/kg which is similar to a typical mobile phone. The results that show there is a general agreement in brain temperature calculated using Pennes equation.

Another work done by Penney & Luebbers (2004) to estimate temperature rise in human tissue from SAR, shows that at 900MHz and SAR of 1.22 W/kg the peak temperature rise was 0.065°C. The peak temperature rise at 1800 MHz, 0.72 W/kg SAR, was 0.036°C.

Comparison of results from this work with other models

Figure 71 shows a comparison of the results of temperature variation in human tissues obtained experimentally and by theoretical calculation in this work and other investigators

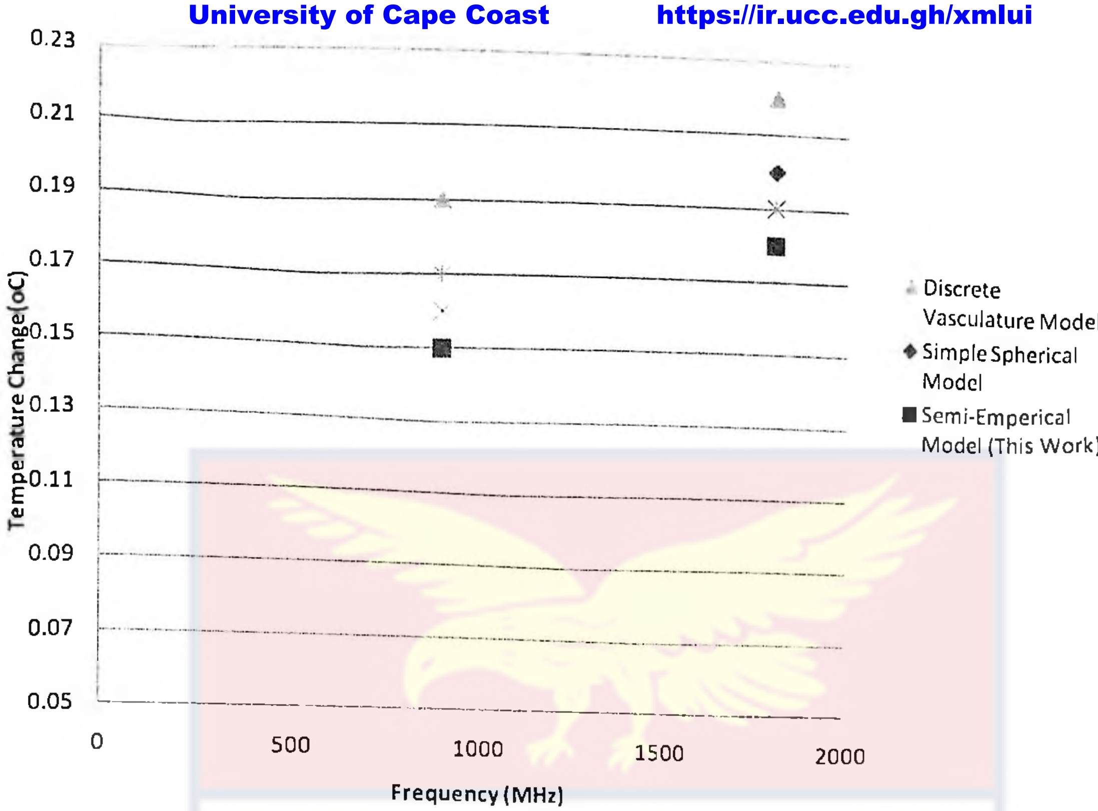

Figure 71: Comparison of results from this work with other models

Source: Laboratory work, 2005

Figure 71 shows that the results obtained from this work were comparable to those obtained in the three other work reported. Using the model at a frequency of 900MHz the maximum temperature change after ten minutes exposure to RF fields from the mobile phone handsets was 0.15°C. The temperature measured using the phantom was 0.18°C. At the frequency of 1800MHz maximum temperature attained were 0.17°C and 0.19°C for the model calculation and phantom measurements respectively.

Comparison with other public exposures and international guidelines

A number of different countries and international organisation have published guidelines for the protection of people from exposure to electromagnetic field radiation. The basis for such guidelines includes the following facts:

Heating can occur as a result of exposure to electromagnetic fields at radiofrequencies.

There are established adverse health effects at exposure level where heating would occur. There is the need to ensure that exposure to RF is restricted to avoid the established effects of exposure to electromagnetic fields.

NRPB Guidelines

The NRPB (now Health Protection Agency) developed guidelines following a comprehensive review of scientific data and on the advice of the NRPB Advisory group on Non-ionising Radiation (NRPB, 1993). The NRPB guidelines are concerned with exposure to electromagnetic fields with frequencies greater than 10 MHz. The guidelines advice basic restrictions on the rate of energy absorption per unit mass of body tissue, or specific absorption rate (SAR) to ensure that harmful temperature rises do not occur in the body in compliance with the NRPB guidelines and this is demonstrated by showing that non of the basic restriction is exceeded. Tables 2 and 3 show NRPB Basic restrictions and investigation levels on exposure to RF fields.

Because SAR are not easily measurable in living matter, the NRPB introduced investigation levels of external electric and magnetic field strength and power density that may be compared directly with measured or calculated exposure levels.

Table 5: NRPB Basic Restrictions on Exposure to Electric and Magnetic Fields in the Frequency Range of 10 MHz to 10 GHz

Description	SAR Value
SAR averaged over the body and over any 15 minutes period	0.4 Wkg^{-1}
SAR averaged over any 10g in the head or foetus and over any 6 minutes period.	10 Wkg^{-1}
SAR averaged over any 100g in the neck and trunk and over any 6 minute period	10 Wkg^{-1}
SAR averaged over any 100g in the limbs and over any 6 minute period	20 Wkg^{-1}
For frequencies between 10 and 300 GHz there is a single basic restriction that applies to any part of the body.	100W kg^{-1}

Source: Health Protection Agency, UK. 1999

International Commission on Non-ionising Radiological Protection (ICNIRP) guidelines

The ICNIRP is an independent scientific organisation responsible for providing guidance and advice on the health hazards of non-ionising radiation exposure. The ICNIRP develops guidelines on limits of exposure to non-ionising radiations and the most recent guidelines on limiting exposure to electromagnetic fields were published in April 1998.

Table 6: Investigation Levels (12 MHz to 300GHz)

Frequency range	Electric field strength (V/m)	Magnetic field strength.H (A/m)	Power density
12 – 200 MHz	50	0.13	6.6
200 – 400 MHz	250	0.66f	$165f^2$
400 – 800 MHz	100	0.26	26
0.8 – 1.55 GHz	125f	0.33f	$41f^2$
1.55 – 300 GHz	194	0.52	100

Source: ICNIRP 1998

Table 7: Reference Levels for time Averaged Exposure to rms Electric and Magnetic Fields (Unperturbed Fields)

Exposure category	Frequency range	E-field strength (V/m rms)	H-field strength (A/m rms)	Equivalent plane wave power flux density Seq (W/m^2)
Occupational	100kHz – 1 MHz	614	1.63/f	-
	1MHz – 10MHz	614/f	1.63/f	$1000/f^2$
	10MHz - 400MHz	61.4	0.163	10
	400 MHz – 2GHz	$3.07f^{0.5}$	$0.00814xf^{0.5}$	f/40
	2GHz – 300GHz	137	0.364	50
General Public	100kHz – 150kHz	86.8	4.86	-
	150kHz – 1MHz	86.8	0.729/f	-
	1MHz – 10MHz	$86.8/f^{0.5}$	0.729/f	-
	10MHz – 400MHz	27.4	0.0729	2
	400MHz – 2GHz	$1.37xf^{0.5}$	$0.00364.f^{0.5}$	f/200
	2GHz – 300 GHz	61.4	0.163	10

Source: ICNIRP, 1998

NOTE

1. f is the frequency in MHz

2. For the specific case of occupational exposure to frequencies below 100kHz and where adverse effects from contact with passively or actively energized conductive objects can be included such that Table 8 would not apply, the derived electric field strength can be increased by a factor of 2.

Table 9: Basic restriction for time varying electric and magnetic fields for frequencies up to 10 GHz

Exposure Characteristics	Frequency range	Current density for head and trunk (mA m^{-2}) (rms)	Whole body average SAR (Wkg^{-1})	Localized SAR (head and trunk) ($W\ kg^{-1}$)	Localized SAR (limbs) ($W\ kg^{-1}$)
Occupational	Up to 1 Hz	40	-	-	-
	1 – 4 Hz	40/f	-	-	-
	4 Hz -1 kHz	10	-	-	-
	1 – 100 kHz	f/100	-	-	-
	100 kHz – 10 MHz	f/100	0.4	10	20
	10 MHz – 10 GHz	-	0.4	10	20
General Public	Up to 1Hz	8	-	-	-
	1 – 4 Hz	8/f	-	-	-
	4 Hz – 1 kHz	2	-	-	-
	1 – 100 kHz	f/500	-	-	-
	100 kHz – 10 MHz	f/500	-	2	4
	10 MHz – 10 GHz	-	0.08	2	4

Source: ICNIRP, 1998

Regulatory Control and RF Radiations from Base Stations and Mobile Phone Handsets

In Ghana, there is no existing legal framework for the regulatory control of RF radiation from mobile phone base station and the handsets. Presently, the NCA only issues guidelines for the installation of Base Stations. These guidelines among other things only emphasize the quality of the service to be provided by the various companies and their coverage. There are no provisions for radiation safety. The EPA has tried to use some of the provisions in the EPA Act to control the installation of Masts. There is the need therefore to enact appropriate laws to regulate the installation of RF antennae. The Radiation Protection Instrument, LI 1559 of 1993 could be amended to take into account non-ionising radiation.

CHAPTER SIX

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

From the study the trend in the number of cell phone usage over the years indicate that the number of cell phones and their base stations is likely to increase. It can therefore be forecast that the level of public exposure to radio frequency fields from these base station is more likely to increase than decrease.

This study has provided a scientific platform for further studies into the interaction of RF fields and other EM fields with human body. This is because modelling the RF fields' interaction with the human body have provided some basic answer to the worried person with regard to exposure to RF fields

Results obtained from some of the base stations in Ghana have given a picture of the extent of RF emissions in some the communities. This information will serve as a starting point for a comprehensive survey of all the base stations in Ghana.

The highest power density values measured for all the base stations were $100\mu W/m^2$ for the 1800MHz frequency and $10\mu W/m^2$ for the 900MHz frequency. These results are much smaller than $4.5 W/m^2$ and $9.0\ W/m^2$ ICNIRP guidance level for 900MHz and 1800MHz respectively.

Measurement made near mobile phone base stations have shown some of the ground level power densities are below the levels recommended by ICNIRP standards but in some cases the power densities measured are much higher (about 20 times higher) than typical values measured in other studies in the UK, Australia and the USA.

This gives an indication that non-existence of guidance level in Ghana provides the opportunity for operators to exceed internationally acceptable level. These results are quite important and give room to show serious concern as the number of mobile phone users increases without a correspondence increase in the number of base stations. Emission levels are bound to go higher. There is the need to increase the number of cell sites in order to improve the quality of signal received at lower antennae power level.

The results obtained from RF Base station will serve as a baseline standard data that could be used the set the National guidance level.

The results obtained from Specific Absorption rate measurement have shown that most of the mobile phone handsets in used in Ghana have SAR values lower than the 1.6W/kg value recommended by the ICNIRP. The maximum SAR value measured was 1.56W/kg and minimum value was 0.12 W/kg. The average SAR of all the phones tested was 1.05W/kg. The results however, show that some of the phones have SAR values which are much higher than the average of all the phones tested. In view of the fact that in an area with weak reception, for example in a closed area, such as a car, the telephone radiates much more powerfully than in an area with a strong reception, this leave room for concern.

This work has demonstrated that SAR for mobile phone could be determined to a high degree of accuracy using simplified laboratory setup.

The results from this work indicate further that even a small distance between the telephone and body reduces exposure significantly. The exposure is smaller if you for example keep the phone in a separate case on your belt instead of keeping it in your pocket.

This work had also demonstrated that the temperature changes in the head of a mobile phone user can be estimated through a semi-empirical model. Theoretical estimate and experimental determination have shown very low temperature variation in the head of the human. It should be emphasis that the quantity of RF energy absorbed by an individual depends on the exposure time. It is therefore necessary to study the biological effects of the long term exposure to RF fields.

This work has demonstrated that the temperature in human tissue can be measured using PMMA phantom filled with laboratory formulated tissue equivalent liquid when temperature is moderated to low temperature. This method is an innovation which gave results which are comparable to results obtained from using other phantoms.

From the results obtained from this work, it can further be concluded that temperature rise in human tissue when exposed RF radiations from mobile phone handsets is few degree Celsius. Highest temperature change measured or calculated was 0.19°C. It should be noted that temperature change increases with increase in exposure time.

There is a very good agreement between the Pennes model and the measured profiles.

The relatively dispersion between calculated values in temperature changes in the human head and the measured values show that estimated temperatures for such computation were based on worst case exposure parameters. The calculated values of power densities do not take into account absorption, reflection and multipath effect of the RF radiations.

The results from this work will help in further development of criteria for exposure guidelines, and the technique developed may be used to assess temperature rise associated with SAR for different types of RF exposure.

Recommendations to Users of Mobile Phone Handsets

In order to reduce personal exposure to RF radiations from mobile phone it is recommended that:

- Information about the most radiation possible (as a SAR value) is given with new phones.
- The use of hands free devices be encouraged in order to stop radiation exposure to the head
- The distance between the body and the telephone is increase as far as practicable as even a small reduction in distance between the telephone and body reduces exposure significantly.
- Parents advice their children to use rather SMS messages than mobile phone calls.
- Parents may restrict the number of their children's mobile phone calls and their duration.
- Parents guide their children to use a hands-free that minimises the exposure of head significantly. When using a hands-free it is recommended to keep the mobile phone at least a few centimetres away from the body.
- The use of mobile phones in weak fields is avoided as much as possible.

Recommendations to Policy Makers

The studies of possible hazards to human health from exposure to radio frequency electromagnetic fields suggest that there is need to control the unwanted exposure as per WHO guidelines.

The radio frequency electromagnetic field generated around Base station antenna may be harmful to the general public and operator/maintenance personnel. The practice of installing Base Stations Antennas needs to be regulated in order to protect the general public from undesired effects caused by Electromagnetic Fields around the Antenna. The following recommendations are therefore made:

- In order to obtain reliable and openly available information about the location and operating characteristics of all base stations in Ghana, it is recommended that a national database be set up by Government giving details of all base stations and their emissions. The data to be captured should include: the name of the company, the grid reference; the height of the antenna above the ground level; the date that transmission started; the frequency range; signal characteristics of transmission; the transmitter power and the maximum output power.
- Although exposure to RF radiation from base station will generally be well below exposure guidelines, it is necessary to prevent access by workers or public to places where the relevant guidelines might be exceeded. It is therefore recommended for the establishment of clearly defined physical exclusion zones around base station antennae that delineate areas within which exposure guidelines may be exceeded. The incorporation of exclusion zones should be part of the planning protocol of the country. Appropriate warning

signs should be incorporated into microcell and picocell transmitters to indicate that they should not be opened when in use.

- There is the need to ensure that base stations are operating within the parameters specified when they are provided. I therefore recommend that an independent, random, ongoing audit of all base stations be carried out to ensure that exposure guidelines are not exceeded outside the marked exclusion zone and that the base stations comply with their agreed specification. If base stations emissions are found to exceed guidance levels, or there is significant departure from the stated characteristics, then the base station should be decommissioned until compliance is demonstrated
- To ensure that the members of the public and workers are not exposed to high RF radiation, operators shall ensure that all radiation are within the International Commission of Non-ionising Radiological Protection (ICNIRP) basic reference levels adopted by the Radiation Protection Board.

In addition to Compliance with ICNIRP guidelines the following precautionary measures shall be adopted for Macro Base Station Antenna:

- Installation of Base Station Antennas within the premises of schools and hospitals may be avoided to the extent possible because children and patients are more susceptible to EMF
- Installation of Base Station Antennas in narrow lanes should be avoided in order to reduce the risks caused by any earth quake or wind related disaster.
- The base station antennas should be at least 3 m away from the nearby building and antennas should not directly face building. Further the lower

end of the antenna should be at least 3 m above the ground or roof. Exclusion zones should be determined and defined by acceptable physical barriers and appropriate gating. The physical barrier shall be a minimum of 3 meters in height within the curtilage of the site to prevent intrusion.

- In case of multiple transmitter sites at a specific locality, sharing of a common tower infrastructure should be explored, as far as possible, which can be coordinated through a nodal agency.
- Access to Base Station antenna site should be prohibited for the general public by suitable means such as wire fencing, locking of the door to the roof, etc. Access to tower site, even for maintenance personnel, should be for a minimum period as far as possible.
- Sign boards/Warnings are to be provided at Base Station antenna sites which should be clearly visible and identifiable. A warning sign should be placed at the entrance of such zone, wherein the survey has shown that RF level exceed the values specified in ICNIRP recommendations.

Siting and Design of Base Stations

It is very important to take several factors in consideration before siting base stations and transmission masts/towers near very close to human settlement. Particular consideration shall to be given to educational institutions, health facilities, residential areas and all other sensitive areas.

- Operator shall comply with all existing laws, regulations and codes regarding local government planning and building regulations

- To prevent obstruction of aircrafts, operators shall comply with Ghana Civil Aviation Authority guidelines on erection of masts and high rise buildings.
- The operator should provide the permitting authority a statement for each site indicating its location, the type of mast, the height of the antenna, the frequency and modulation characteristics, and details of power output. Applications should be accompanied by information relating to proper access to the Base station including driveways on property and right of ways.
- The site area of the base station shall be a minimum of 400 square metres for self support towers. The foremost part of each Mast/Tower shall be a minimum distance of 6.1 metres from the physical barrier. Where the size and setbacks proposed do not meet the required standard, a written explanation shall be submitted along with the application.
- Operators shall consider the use of materials, colours and design that would minimize obtrusiveness. In urban areas the preference shall be for towers to be located on existing buildings rather than creating new installations/sites.
- Any change to an existing base station which increases its height and base shall be subject to the normal planning process as if it were a new development.
- Where possible the proposed development should be designed to blend into the environment so as to minimize its visual impact on the environment. To this end the telecommunications industry and the relevant government agencies shall continue to explore different designs solutions,

type of material and colour used. The operators may be asked in sensitive locations to consider different types of apparatus and design solutions.

- All electrical installation shall be in accordance with the requirements of Electricity Corporation of Ghana and Ghana Institute of Engineers
- Structural integrity of the tower shall be inspected and certified by the AESL or registered professional engineer every five years.

Recommendations for Future Research

On the basis of current state of knowledge, it is recommended that priority be given to a number of areas of research related particularly to signal from mobile phone handsets. These should include the following:

- Effect on brain function
- Consequences of exposure to pulsed signals
- Improvement in Radio frequency Dosimetry
- The possible impact on health of subcellular changes induced by RF radiation
- Psychological and sociological studies related to the use of mobile phones

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APPENDICES

APPENDIX A

BASIC PROGRAMME FOR CALCULATING RF POWER DENSITY
DEVELOPED BY JOSEPH K AMOAKO AT RADIATION PROTECTION BOARD/ GHANA ATOMIC ENERGY COMMISSION

```
10 COLOR 15,1,4:CLS:PRINT:PRINT:PRINT:REM REV. 2.1 - 27/08/2007
20 PRINT "                MAIN BEAM POWER DENSITY ESTIMATION PROGRAM"
30 PRINT "          FOR ROUTINE EVALUATION OF R.F. SAFETY COMPLIANCE"
40 PRINT:PRINT
50 PRINT "This program uses the formulas given in FCC OET Bulletin
No. 65"
60 PRINT "to estimate power density in the main lobe of an antenna,
with"
70 PRINT "use of the EPA-recommended ground reflection factor as an
option."
80 PRINT:PRINT "This program is intended for far field calculations.
It may"
90 PRINT "overestimate the actual field strength of high-gain
antennas in"
100 PRINT "the near field (within several wavelengths of the
antenna)."
110 PRINT "However, it may also underestimate the strength of fields
that may"
120 PRINT "be encountered in `hot spots' in the near field.  No
computer"
130 PRINT "program can predict where wiring or reflective objects may
create"
140 PRINT "hot spots in your particular installation.":PRINT
150 PRINT "This is a public domain program by Wayne Overbeck,
N6NB":PRINT
160 INPUT "WHAT IS THE AVERAGE POWER AT THE ANTENNA (IN WATTS)";
WATTS
170 PWR = 1000 * WATTS
180 PRINT:PRINT "WHAT IS THE ANTENNA GAIN IN DBI?"
190 INPUT "(Enter 2.2 for dipoles; add 2.2 for antennas rated in
DBD): ",GAIN
200 REM NOW CALCULATING EIRP IN MILLIWATTS
210 EIRP = PWR * (10 ^ (GAIN / 10))
220 PRINT:INPUT "WHAT IS THE DISTANCE TO AREA OF INTEREST FROM
ANTENNA CENTER IN FEET"; FT
230 REM NOW CONVERTING TO CM
240 DX = FT * 30.48
250 PRINT:INPUT "WHAT IS THE FREQUENCY IN MHZ";F
260 IF F<1.34 THEN STD1=100:STD2=100:GOTO 330
270 IF F<3 THEN STD1=100:STD2=180/((F)^2):GOTO 330
280 IF F<30 THEN STD1=900/((F)^2):STD2=180/((F)^2):GOTO 330
290 IF F<300 THEN STD1=1:STD2=.2:GOTO 330
300 IF F<1500 THEN STD1=F/300:STD2=F/1500:GOTO 330
310 IF F<100000! THEN STD1=5:STD2=1:GOTO 330
320 PRINT "THE FCC DOES NOT HAVE EXPOSURE LIMITS ABOVE 100 GHZ":GOTO
250
330 PRINT:PRINT "NOW, DO YOU WISH TO INCLUDE EFFECTS OF GROUND
REFLECTIONS?"
332 PRINT "(Ground effects need not be included in most main-beam
calculations"
340 PRINT "but including them may yield more accurate results with
very low"
```



```
342 PRINT "antennas, non-directional antennas, and calculations below the"
350 INPUT "main lobe of directional antennas.)  INCLUDE GROUND EFFECTS (Y/N)";G$
370 GF=.25:GR$="WITHOUT":IF G$="Y" THEN GF=.64:GR$="WITH"
380 IF G$="y" THEN GF=.64:GR$="WITH"
390 PWRDENS = (GF * EIRP) / (3.14159 * (DX ^ 2))
400 PWRDENS=(INT((PWRDENS*10000)+.5))/10000
410
DX1=SQR((GF*EIRP)/(STD1*3.14159)):DX1=DX1/30.48:DX1=(INT((DX1*10)+.5)
)/10
420
DX2=SQR((GF*EIRP)/(STD2*3.14159)):DX2=DX2/30.48:DX2=(INT((DX2*10)+.5)
)/10
430 STD1=(INT((STD1*100)+.5))/100:STD2=(INT((STD2*100)+.5))/100
432 CLS:PRINT "THE RESULTS ARE AS FOLLOWS:":PRINT
440 PRINT "WITH";WATTS;"WATTS AND";GAIN;"DBI GAIN ";GR$;" GROUND REFLECTIONS, AT";FT;"FEET"
450 PRINT "FROM THE ANTENNA CENTER THE ESTIMATED POWER DENSITY IS";PWRDENS;"MW/CM2.":PRINT
460 PRINT "AT";F;"MHZ, THE MAXIMUM PERMISSIBLE EXPOSURE (MPE) IN `CONTROLLED"
470 PRINT "ENVIRONMENTS' (SUCH AS YOUR OWN HOUSEHOLD OR CAR) IS"; STD1; "MW/CM2."
480 PRINT "THE MPE IN `UNCONTROLLED ENVIRONMENTS' (SUCH AS NEIGHBORS' PROPERTY)"
490 PRINT "IS"; STD2; "MW/CM2.  THIS INSTALLATION WOULD MEET THE CONTROLLED MPE"
500 PRINT "LIMIT AT";DX1;"FEET AND THE UNCONTROLLED LIMIT AT";DX2;"FEET."
510 PRINT:PRINT "ALTERNATE CALCULATION METHODS:"
520 PRINT "    1) Exposure is averaged over six minutes in controlled environments"
530 PRINT "and 30 minutes in uncontrolled environments.  If you never transmit more"
540 PRINT "than three minutes in any six-minute period, divide the power density"
550 PRINT "shown above by two when calculating the power density in your own house-"
560 PRINT "hold.  Also divide by two when calculating fields beyond your property"
570 PRINT "if you never transmit more than 15 minutes in any 30-minute period."
580 PRINT "    2) If you wish to estimate the power density at a point below the main"
590 PRINT "lobe of a directional antenna, and if the antenna's vertical pattern is"
600 PRINT "known, recalculate using the antenna's gain in the relevant direction."
```


APPENDIX B

```
PROGRAM TISSUE
IMPLICIT NONE
!This solves for the temperature in a tissue with time in 1-dimension
!Developed at the Ghana Atomic Energy Commission on 5/02/08
!The heat generated by metabolism is assumed to be negligible mu=0
REAL:: p,q,rhot,rhob,c,cb,w,temp,t,mu,sar,tart,k,a,d,h,f
5 PRINT*,"THIS APPLICATION SOLVES FOR THE TEMPERATURE IN
TISSUE WITH TIME"
PRINT*,"------------------------------------------------------------"
PRINT*
PRINT*,"ENTER THE DENSITY OF THE TISSUE"
READ*,rhot
PRINT*,"ENTER THE DENSITY OF THE BLOOD"
READ*,rhob
PRINT*,"ENTER THE SPECIFIC HEAT OF THE TISSUE"
READ*,c
PRINT*,"ENTER THE SPECIFIC HEAT OF BLOOD"
READ*,cb
PRINT*,"ENTER THE TISSUE'S THERMAL CONDUCTIVITY"
READ*,k
PRINT*,"ENTER THE RATE OF BLOOD FLOW"
READ*,w
PRINT*,"ENTER THE SPECIFIC ABSORPTION RATE"
READ*,sar
PRINT*,"ENTER THE INTIAL AND FINAL TIME; AND STEP LENGTH"
READ*,a,d,h
tart=37
mu=0
p=(k-w*cb)/(rhot*c)
PRINT*,"p",p
q=(w*cb*tart+rhob*sar+mu)/(rhot*c)
PRINT*,"q",q
PRINT*
PRINT*,"TIME(s)                TEMPERATURE(C)"
PRINT*,"============================================"
DO t=a,d,h
temp=37*exp(p*t)+q*t
PRINT*,t,temp
END DO
PRINT*,"TO RUN AGAIN, PRESS 1, ELSE PRESS ANY OTHER NUMBER"
READ*,f
IF (f==1) THEN
GOTO 5
ELSE
END IF
READ*
END PROGRAM TISSUE
```


APPENDIX C

EMPIRICAL SOLUTION TO MATHEMATICAL MODEL

$$\frac{\partial T}{\partial t} = \frac{1}{\rho_t G}\left[\nabla K_k \ \nabla T - W_b \ C_b T + W_b \ C_b \ T_{art} + \rho.SAR \ + M\right]$$

Assuming superficial heating of the skin hence variation of T with skin depth is negligible.

For one dimensional considerations

$$\frac{\partial T}{\partial t} = \frac{1}{\rho_t C_t}\left[(K_k - W_b \ C_b)T + W_b \ C_b \ T_{body} + \rho SAR + M\right]$$

$$\Rightarrow \frac{\partial T}{\partial t} = \frac{(K_K - W_b \ C_b)}{\rho_t \ C_t}T + \frac{1}{\rho_t C_t}\left[W_b \ C_b \ T_{body} + \rho SAR + M\right]$$

$Since \ K_k, W_b \ C_b, \rho_t, G, \rho \ T_{body} \ \ M \ are \ constarts$

$$Let \ \frac{K_k - W_b \ C_b}{\rho_t C_t} = p \ and$$

$$\frac{1}{\rho_t C_t}\left[W_b C_b \ T_{art} + \rho SAR + M\right] = q$$

$$\Rightarrow \frac{\partial T}{\partial t} = \rho T + q \qquad (1)$$

$$\rho(t) = \rho, \ q(t) = q$$

$$U(t) = U_c(t) + U\rho(t)$$

$$U_c(t) = Q\ell \int_{to}^{t} \rho dt = Q\ell \ \rho^{(t-to)} = Q\ell^{\rho t}$$

$$q(t) = q$$

$$Let \ T = \alpha t \qquad (2)$$

$$\Rightarrow \frac{\partial T}{\partial t} = \alpha \qquad (3)$$

$Substituting \ (2) \ and \ (3) \ in \ (1) \ gives$

$$\alpha = \rho \alpha t + q$$

Comparing coefficients

$$q = \alpha$$
$$\rho\alpha = 0$$
$$\rho = 0$$
$$U\rho(t) = qt$$

But General Solution in $U(t) = U_c(t) + U\rho(t)$

$$\Rightarrow U(t) = Q\exp(\rho t) + qt$$
$$T_{body} \leq 24^{o}C \text{ or } 37^{o}C$$
$$T(t) = Q\exp(\rho t) + qt \qquad t_o = 0$$
$$37^{o}C = Q$$
$$\therefore T(t) = 37\exp(\rho t) + qt \qquad (4)$$

APPENDIX D

TABLE 10: Sites and Antennae Description

SITE	TYPE OF ANTENNA	MEASUREMENT POINT
A	900 and 1800 MHz GSM sector antennae located at 50m from the ground	60 m from the antenna
B	Six 900 and four1800 MHz sector antennae mounted on school premises	
B!		Classroom
B2		Playground 30 m from mast
C		
D	Six 1800 MHz and six 900 MHz sector antenna mounted at 18 m and 22 m respectively	
D1		Garden 80m from antenna
D2		Near bed room at 80m from the antenna
D3		70 m from tower
D4		Near window of nearby building
D5		33 m from tower
D6		

D7		Nearby Garden 32 m from tower
D8		Skylight
E	3 GSM 900MHz dual polar antenna	Located Near School Building
E1		80 m from the antenna
E2		60 m from antenna
E3		Playing field 40 m from the antenna
F		
F1	12 GSM 900 MHz 35m above the ground	50m from the antenna
F2	GSM 900 Omni directional antenna and 6 GSM 1800 sector antenna 55 m above the ground	
F3		
G		
H	G SM 1800 sector antennas mounted 20 m above the ground level at the top of a stub mast on the roof	
H1		110 m from the base of the antenna

J9		
K	GSM 900 and GSM 1800	35 m above the ground
K1		8 m from the antenna
K2		10 m from the antenna
L	Tower of height 30 m on 5m GSM with 6 antenna	
L1		Ground distance at 230 m with clear view
L2	3 GSM dual Polar antenna sector antenna 17m above the ground	40 m from the antenna
L3		140 m and with clear view of the antenna
M	GSM 1800 Dual Polar Sector Antenna	Located on top of a storey classroom
M1		Playing field 140 m clear from antenna
M2		Top storey classroom beneath the stub mast
N	GSM 900MHz	
N1		13 m from the antennas
N2		Top of storey 20 m from antennas
N3		Classroom located 20 m

		from antenna
O	Two-storey Building with six GSM 900 sector and GSM1800	mounted 17 m above ground level
O1		150 m from antenna
O2		Ground floor room 1 at 20 m from antenna
O3		Ground floor 20 m from antenna
O4		Ground floor room 2 at 20 m from antenna
O5		Car park at distance of 50 m from the antenna
O6		First floor room in an adjoining building of a distance of 15 m from antenna
O7		First floor room 16 m from antennas
O8		First floor room 20 m from antennas
O9		Second floor classroom in neighbour 40 m from antennas
O10		40 m from the antenna

O11			Play ground 50 m from the antenna
O12			Playing field 20 m from antenna

S/N	LOCATION	LONGITUDES	LATITUDES
1.	Adweso	000°15'34"W	06°03'48"N
2.	Koforidua Central Market	000°15'34"W	06°03'48"N
3.	Kwahu Tafo	000°39'40.8"W	06°39'10.3"N
4.	Abomosu	000°43'47.6"W	06°18'08.7"N
5.	Asuboa	000°52'00"W	05°53'08.0"N
6.	Apedwa Junction	000°29'35"W	06°07'37"N
7.	Adoagyiri	000°21'17.67"W	05°49'38.70"N
8.	Kwahu Asakraka	000°42'05.4"W	06°37'45.0"N
9.	Kwahu Praso	000°54'23.2"W	06°37'12.2"N
10	Nkurakan	000°12'34.4"W	06°07'46.5"N
11.	Akim Aperade	001°05'57.0"W	05°47'15.8"N
12.	Akim Akrosu	000°46'19.5"W	06°46'08.9"N
13.	Osiem	000°25'45.5"W	06°15'11.9"N
14.	Kwahu Nkwatia	000°43'40.6"W	06°38'02.7"N
15.	Oyoko	000°17'22.1"W	06°08'37.0"N
16.	Akim Takyiman	000°40'7.4"W	06°10'19.8"N
17.	Adawso	000°12'38.5"W	05°56'48.1"N
18.	Oda Nkwanta	001°00'51.5"W	05°58'57.2"N
19.	Kwahu Pepease	000°44'32.6"W	06°41'30.5"N
20.	Teacher Mante	000°23'32.00"W	05°54'07"N
21.	Asene	000°56'10.5"W	05°55'28.3"N
22.	Frankadua	000°10'33"W	06°20'27"N
23.	Asuboi	000°24'58"W	05°57'00"N

S/N	LOCATION	LONGITUDES	LATITUDES
1.	Kenyase	002°23'27"W	06°59'01"N
2.	Acherensua	002°17'50"W	06°58'34"N
3.	Bonsu	003°01'02"W	06°19'12"N
4.	Seikwa	002°31'07.0"W	07°43'30.0"N
5.	Badu	002°14'06.5"W	07°41'11.8"N
6.	Berekum 2 (kato)	002°34'06"W	07°26'02"N
7.	Jinijini	002°38'57.5"W	07°26'52.4"N
8.	Aboabo No. 3	002°48'33"W	07°12'15.5"N
9.	Amasu	002°47'08".4W	07°13'34.0"N

S/N	LOCATION	LONGITUDE	LATITUDES
1.	Okorase	000°15'44.16"W	06°02'15.32"N
2.	Begoro	000°22'46.98"W	06°22'54.99"N
3.	Adeiso	000°28'54.99"W	05°47'56.00"N
4.	Mame Krobo	000°26'6.99"W	06°56'53.99"N
5.	Achiase	000°59'52.01"W	05°50'1.99"N

No.	Site Name	Region	Latitude	Longitude
1	Opeibea	Greater Accra	05°35'56"N	000°10'47"W
2	New Achimota	Greater Accra	05°37'58"N	000°15'11"W
3	Children's Hospital	Greater Accra	05°32'43"N	000°12'44"W
4	Kokomlemle	Greater Accra	05°34'37"N	000°12'43"W

S/N	LOCATION	LONGITUDE	LATITUDE
1.	Larabanga	9°13'01.601"N	1°59'21.731"W
2.	Damango Mpeasim	9°05'07.320"N	1°49'16.541"W
3.	Nasia	10°09'32.634"N	0°48'00.634"W
4.	Kpandai	8°28'27.527"N	0°01'20.323"W
5.	Salaga 2	8°33'01.433"N	0°31'31.376"W
6.	Diare-Kadia	9°52'08.052"N	0°52'19.787"W
7.	Pong-Tamale	9°41'33.209"N	0°49'50.334"W
8.	Napei	9°09'06.886"N	1°08'48.116"W
9.	Fufulso Junction	9°07'32.628"N	1°16'34.510"W
10.	Busunu	9°09'50.389"N	1°30'64.0"W
11.	Sankpala	9°15'59.905"N	0°00'33.793"W
12.	Langbesi	10°24'27.670"N	0°33'57.292"W
13.	Wulugu	10°26'37.742"N	1°02'54.352"W

S/N	LOCATION	LONGITUDE	LATITUDE
1.	Techire	002°10'26"W	07°13'47"N
2.	Kintampo II	001°43'28"W	08°03'14"N
3.	Duadaso No. 1&2	002°3747.9W	07°54'07.6"N
4.	Krabonso	001°4903W	07°58'31"N
5.	Tuobodom	001°5417.3W	07°38'13.2"N
6.	Techiman Nsuta	002°0435.3W	07°32'00.7"N
7.	Techiman Market	001°5603W	07°35'17"N
8.	Wenchi II	002°0637W	07°43'56"N
9.	Atronie	0022426W	07°09'09"N
10.	Yamfo	0021429.0W	07°13'24.0"N
11.	Sunyani Market	002°18'49"W	07°19'49"N

S/N	LOCATION	LONGITUDE	LATITUDE
1.	Amamoma	001°07'40"W	05°06'33"N
2.	Essuakyir	000°53'30"W	05°18'23"N
3.	Assin Fosu	001°45'40"W	05°42'25"N
4.	Assin Andoe	001°05'35"W	05°31'56"N
5.	Abeadze Dominase	001°05'35"W	05°21'09"N
6.	Essiam Ajumako	000°59'30".47"W	05°24'33.91"N
7.	Breman Bedum	001°00'36"W	05°31'35"N
8.	Abaasa	000°56'47"W	05°21'52"N
9.	Essuehyia	000°53'30"W	05°18'23"N

APPENDIX E

PUBLICATIONS

1. J. K. Amoako, J. J. Fletcher and E. O. Darko

   Measurement and Analysis of Radio frequency Radiations from some Mobile Phone Base stations in Ghana, Radiation Protection Dosimetry, Radiation Protection Dosimetry (2009), pp 1-5

Radiation Protection Dosimetry Advance Access published July 7, 2009

Radiation Protection Dosimetry (2009), pp. 1–5

doi:10.1093/rpd/ncp115

MEASUREMENT AND ANALYSIS OF RADIOFREQUENCY RADIATIONS FROM SOME MOBILE PHONE BASE STATIONS IN GHANA

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Received December 3 2008, revised June 1 2009, accepted June 13 2009

A survey of the radiofrequency electromagnetic radiation at public access points in the vicinity of 50 cellular phone base stations has been carried out. The primary objective was to measure and analyse the electromagnetic field strength levels emitted by antennae installed and operated by the Ghana Telecommunications Company. On all the sites measurements were made using a hand-held spectrum analyser to determine the electric field level with the 900 and 1800 MHz frequency bands. The results indicated that power densities at public access points varied from as low as 0.01 µW m^{-2} to as high as 10 µW m^{-2} for the frequency of 900 MHz. At a transmission frequency of 1800 MHz, the variation of power densities is from 0.01 to 100 µW m^{-2}. The results were found to be in compliant with the International Commission on Non-ionizing Radiological Protection guidance level but were 20 times higher than the results generally obtained for such a practice elsewhere. There is therefore a need to re-assess the situation to ensure reduction in the present level as an increase in mobile phone usage is envisaged within the next few years.

INTRODUCTION

There has been a rapid increase in the number of mobile phone subscribers in Ghana in recent times due to the liberalisation of the telecommunication industry. Statistics show that as on May 2008 the number of mobile phone users in the country is well over 8 million. This increase has led to the corresponding rapid deployment of a number of cell sites with the installation of many antennae in the country. There are several hundreds of cell sites all round the country. Several of these cell sites are installed in densely populated residential areas and near schools.

This has heightened the public concern on health and safety issues as far as the radiofrequency (RF) radiation from these antennae is concerned.

Some of these concerns have been reported in published results of scientific articles in recent times, even though review of several published results does not provide evidence to show the link between cancers and RF radiation[1–3]. There are suggestions to the fact that there are some biological effects due to exposure to RF radiation[1]. At the moment there are no clues to any chronic effect of these emissions[2,3]. Many countries have resorted to precautionary approaches to allay public fears. In Ghana, there is no existing regulatory framework as far as the safety of non-ionising radiation is concerned. The existing legal framework on Radiation Protection LI 1559 of 1993 provides only for the control of ionising radiation.

The primary objective of this work was to measure the level of RF radiation emitted by some mobile phone base stations installed by Ghana Telecommunication (GT) Company and to assess the level of compliance with standards set by the International Commission on Non-ionizing Radiological Protection (ICNIRP) and other international regulatory bodies[4–9]. The results of this work will provide a baseline data to enable the appropriate safety regulatory framework to be put in place in Ghana.

MATERIALS AND METHODS

The survey covered 50 sites of the GT Company networks as shown in Figure 1. The selected sites were chosen to cover those close to schools, hospitals and highly populated residential areas. Measurements were made at public access locations at all the sites.

All measurements were made using Anritsu model MS 2601A spectrum analyser. The equipment allows the RF signal to be analysed. Data from the spectrum analyser were loaded on to a laptop computer. At all sites, log-periodic omni-directional antennae were used. The antenna was calibrated to determine the gain factor that was used for the calculation of the power densities of RF emissions.

Using a Global Positioning System, locations of the various base stations were mapped. Measurements were made in a location that was 1.5 m above the

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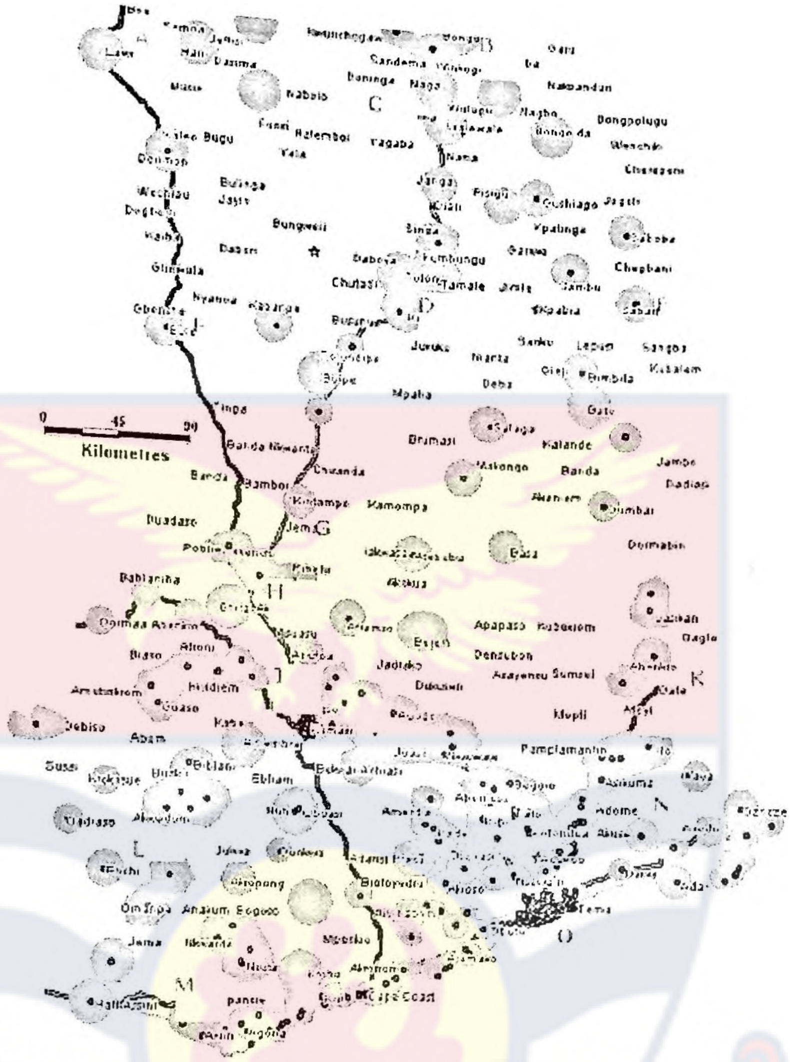

Figure 1. Map of Ghana showing mobile phone base station sites where measurements were taken.

ground so as to maintain a direct line of sight with the RF source.

The signals were measured during the day over a period of 3 h at a distance of about 300 m from each base station. Measurements were done during the peak period of the day. Data available at the GT office show that peak periods during the day were mid-day that is between 10.00 a.m. and 1.00 p.m.

and evenings between 4.30 p.m. and 7.30 p.m. Six minute weighted averaging time was used for all measurements as recommended by international standards for RF exposure. For the calculation of total field strength from individual peaks, it was necessary to sum the power due to each signal and then convert the resultant power back into field strength. The following equation was used to convert the received voltage V_{rx} into electric field strength, E, corresponding to the signal:

$$E = V_{rx} \cdot F \cdot 10^{L/10}, \quad (1)$$

where F is the antenna factor (m^{-1}) and L the loss in the cable (dB).

It is the quantities that are expressed in logarithms and the units in decibels. Equation 1 becomes:

$$E_{dB\mu V/m} = V_{dB\mu V} - F_{dBm^{-1}} - \frac{L}{10}. \quad (2)$$

The intrinsic impedance of free space, η, was then assumed to be equal to 377 Ω so that the following equation could be used to calculate the power density, S, of each signal.

$$S = \frac{E^2}{\eta} \quad (3)$$

The value of the antenna factor used for converting the voltage into electric field intensity, E, was 20 dB.

RESULTS AND DISCUSSIONS

The results showing how electromagnetic radiation from different cell sites complies with the ICNIRP guidance levels are presented in Figures 2–7.

The results of field measurements at various cell sites used for this study show power density variation of as low as 0.01 $\mu W m^{-2}$ to as high as 10 $\mu W m^{-2}$ for the frequency of 900 MHz. At a transmission frequency of 1800 MHz, the variation of power densities is from 0.01 to 100 $\mu W m^{-2}$.

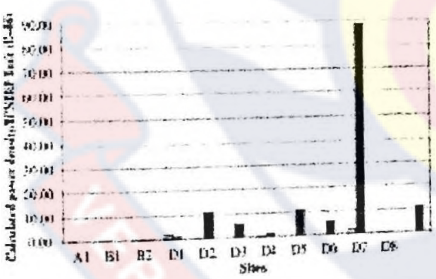

Figure 2. Level of compliance of site measurement with ICNIRP limit at sites A–D. Open bars represent 900 MHz/ICNIRP and filled bars 1800 MHz/ICNIRP.

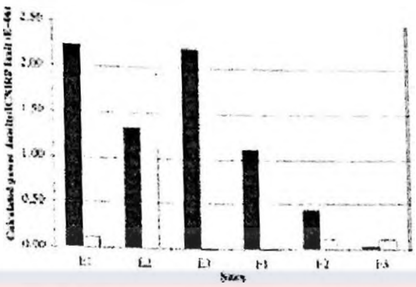

Figure 3. Level of compliance of site measurement with ICNIRP limit at sites E and F. Filled bars represent 900 MHz and open bars 1800 MHz.

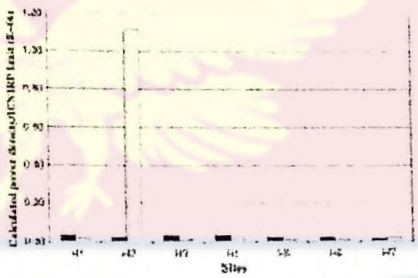

Figure 4. Level of compliance of site measurement with ICNIRP limit at site H. Filled bars represent 900 MHz and open bars 1800 MHz.

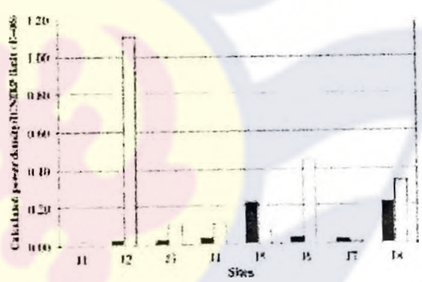

Figure 5. Level of compliance of site measurement with ICNIRP limit at site J. Filled bars represent 900 MHz and open bars 1800 MHz.

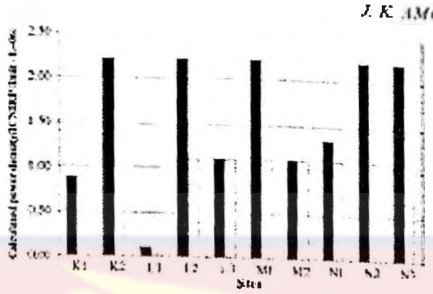

Figure 6. Level of compliance of site measurement with ICNIRP limit at sites K-N. Filled bars represent 900 MHz and open bars 1800 MHz.

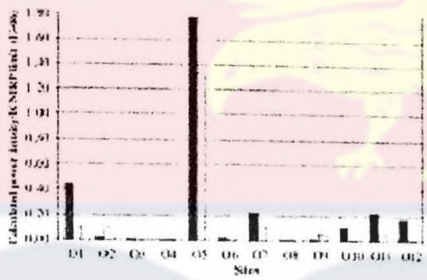

Figure 7. Level of compliance of site measurement with ICNIRP limit at site O. Filled bars represent 900 MHz and open bars 1800 MHz.

The lowest power density value was recorded at sites O4 and H2 for the 900 MHz frequency and the highest value at the same frequency was recorded at sites D1, E1, E3, J8, M1, N2 and N3. The difference may account for the location of these cell sites. Higher field levels were recorded at cell sites that are remote, serving several communities with large numbers of subscribers as compared with cell sites that are very close to each other. Possible reason accounting for higher field levels at some of the remote areas may be due to the fact that operators are forced to operate at maximum permissible levels of the various antennae. At a frequency of 1800 MHz, the lowest power density values were recorded at site O4 and the highest recorded at sites D5 and D7 as shown in Figure 2.

The low values of field measurements at most of the cell sites do not discount the possibility of biological effects on the population. One mechanism that could lead to biological effects at these low fields is that proposed by Frohlich[6,7] and which relies on the existence in biological tissues of a particular coherent state of mechanical vibration. This phenomenon cannot be ruled out. Therefore, there is a need for further work to investigate the proposed mechanism.

A critical look at Figures 1–6 shows very high levels of compliance with the ICNIRP limits[4]. The ICNIRP guidelines that set reference levels for general public for frequencies of 900 and 1800 MHz are 4.5 and 9.0 W m^{-2}, respectively[4]. However at sites D7, K1, L2, M1, N2, N3 for frequency of 900 MHz, the level of compliance need to be improved as there were indications of deviation from the general trend. The results generally show that level of compliance with the ICNIRP limit was about 0.01 %. These results may appear low, but a survey in Australia done by Bangay and Henderson[8,9] shows that exposure was 0.0021 % of the ICNIRP limit; this is a cause for concern as exposure levels in Ghana appear to be close to 20 times higher than that of Australia.

CONCLUSION

Results obtained from some of these base stations in Ghana have given a picture of the extent of RF emissions within the communities. This information will serve as a starting point for a comprehensive survey of all the base stations in Ghana.

Measurements made near mobile phone base stations have shown that the ground level power densities are below the limits recommended by the RF safety standards. The results however shows that in some cases the power densities measured are much higher (about 20 times higher) than typical values measured in other studies in the UK, Australia and the USA. This gives an indication that non-existence of guidance level in Ghana provides the opportunity for operators to exceed ICNIRP reference levels for limiting the exposures from electromagnetic fields. These results are quite important and give room for serious concern as the number of mobile phone users increases without a corresponding increase in the number of base stations. Emission levels are bound to go higher. There is a need to increase the number of cell sites in order to improve the quality of signal received at a lower antennae power level.

ACKNOWLEDGEMENTS

The authors would like to express their thanks to the Radiation Protection Institute of Ghana Atomic Energy Commission for providing the funds and logistics that enable us to undertake this work.

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