APPROVAL FORM

The signatory below confirms that they supervised Tapiwa Mupakati on a dissertation titled: **A MODEL TO DETERMINE SAFE ZONE MARGIN FOR MOBILE BASE STATION SITES IN RESIDENTIAL AREAS WITH REFERENCE TO EMARALD HILL AND GREENCROFT RESIDENCES, HARARE, ZIMBABWE.** The dissertation was submitted in partial fulfilment of the requirements of the Bachelor of Science Honours Degree in Telecommunications at Midlands State University.

……………………………………………… ……………………….

SUPERVISOR DATE

DECLARATION

I Tapiwa Mupakati declares that I am the sole author of this project and I hereby grant permission to the Midlands State University Library to produce single copies of this dissertation and to lend or sell such copies for private, scholarly or scientific research purposes only, however, author maintains all other publication.

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DEDICATION

To my mother and the Mupakati family.

ACKNOWLEDGEMENTS

Firstly I would like to thank the Almighty God for taking me through this research exercise. It had ups and downs but the Lord provided strength, courage, belief, hope, trust and motivation when it mattered most.

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ABSTRACT

The issue of EMF radiation has for years been received with mixed feelings by all stakeholders. In this study, the relationship between EMF exposure levels with distance from the mobile base station has been illustrated. The contributions of each frequency band used by mobile operators in Zimbabwe, with reference to the area of study has been assessed and compared using well informed data and assumptions. Graphs have been used to clearly show such contributions and matlab was used for simulation purposes. Exposure to single sources and two sources or more was considered in simulating exposure levels. The research also deduces the safe zone margin from mobile base stations with particular reference to the area of study. Exposure level values obtained were also compared with ICNIRP guidelines and recommendations have been given to various stakeholders.

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CHAPTER 1

LITERATURE REVIEW

1.1 Introduction

This research is focused on determining the safe distance margin from a cellular mobile base station such that the radiated EMF from the mobile base station transmitters will not be harmful to humans who stay close to the base station in the long run. The safe distance margin can be viewed as an exclusion zone from a mobile base station premise that a house of residence can be termed ‘safe’ from possible harm from long time exposure to mobile base station transmitter radiation. Power density for various points from the mobile cellular tower is going to be determined for the three bands in under the scope of this research: 900MHz, 1800MHz and 2100 MHz to model the EMF exposure levels currently experienced by humans in places where mobile base station towers have been built in their areas of residences.

This chapter is going to introduce various aspects that are going to be covered in detail in the chapters to follow.

1.2 Background

An electromagnetic field refers to a field of force which is generated by electrical charges or magnetic fields. EMF can also be considered as radiation when radiation energy is produced from the sources of the fields. This research is based on non-ionising radiation from mobile base station transmitters [1]. Electromagnetic Radiation (EMR) is a form of energy emitted and absorbed by charged particles which can be harmful to the human body depending on the radiated power density and also the distance from the transmitting element [2]. It thus includes the far field region of the transmitter. People have increasingly been worried about the possible health hazards that are likely to be emanating from EMR. Electromagnetic waves cannot be directly perceived by human ears.

In Zimbabwe, the spectrum range (8.3KHz – 3000GHz) has been divided into a number of bands and general purposes specified for each band by the Postal and Telecommunication Regulatory Authority of Zimbabwe (POTRAZ) which administers the use of Spectrum by all services, applications and systems in Zimbabwe in accordance with the Postal and Telecommunications Act [Chapter 12:05of 2000] [3].

At radio and microwave frequencies, EMR interacts with matter largely as a bulk collection of charges which are spread out over large numbers of affected atoms. In electrical conductors, such induced bulk movement of charges (electric currents) result in absorption of the EMR, or else separations of charges that cause generation of new EMR (effective reflection of the EMR). An example is absorption or emission of radio waves by antennas, or absorption of microwaves by water or other molecules with an electric dipole moment, as for example inside a microwave oven. These interactions produce either electric currents or heat, or both.

EMF occurs in naturally and so has always been present on this planet. Nevertheless, exposure to man-made sources increased drastically in the past decades due to advances in technology.

1.2.1 Radio and microwave

1.2.1.1 Ionizing radiation

This type of radiation has the much needed energy to cause ionisation. This comes as a process that strips electrons from their molecules and atoms. The level of energy is therefore able to change the body's chemical reactions and thus cause damage to biological tissues. Ionising radiation has established adverse health effects [4] .

1.2.1.2 Non ionizing radiation

This type of radiation does not have the much needed energy to effect a chemical change in matter. It is however able to cause a thermal effect in matter or induce electric current or both [4]. Considering a cell phone user, majority of the heating occurs on the head's surface which results in the head's temperature increasing by a small percentage of a degree. The excess heat is however disposed by brain blood circulation through increase of the local blood flow. The major problem is on the eye's cornea which lakes a mechanism to regulate temperature [4] .

1.2.1.3 Specific Absorption Rate (SAR)

SAR measures RF energy amounts absorbed by body tissues. It gives the average rate at which energy is absorbed by the tissue (W/kg). The measurement determines mobile phone safety guidelines. The exposure limits consider heat removal capabilities of the body for that energy absorbed from mobile phones [4].

1.2.1.4 Mobile Cellular Tower Transmission Elements

It is not the tower itself which is of concern, but the transmitting equipment which is mounted on the tower. Tower height normally depends on the coverage that the transmitting elements have to cover. For mobile operators in Zimbabwe, tower heights range mainly from 25m and can go as high as 95m for heavy duty towers. Antennas mounted come as monopole, directional (dish) and dipole antennas. Monopoles are now rarely used even in the rural areas where they are used to provide simple coverage to small subscriber bases with which subscribers are distributed in all directions. Directional antennas are used for site to site transmission for frequencies: 8GHz, 15GHz, 18GHz, 23GHz and 38 GHz depending on hop length, with higher frequencies being used for shorter hop lengths due to frequency-attenuation variation relationship. These antenna gains depend on antenna diameters. These diameters come as 0.3m,0.6m,0.9m,1.2m,2.4m and 3.4m though from experience the researcher has only managed to use up to 2.4m diameter antennas.

Panel antennas are used for providing radio resources to mobile stations. These are the main sources of radiation from mobile towers and come at different electrical and mechanical properties. They come at different Frequency bands of operation which in turn determines the size and weight of the antennae. (Lower frequency will mean higher wave lengths and thus more dipoles used in constructing the antenna and thus greater weight and size and also radiated power). This will mean therefore that an antenna meant for 900MHz is larger than that for 1800MHz and 2100MHz respectively. However, most of the antennas are now coming as multi band antennas such that one antenna can support more than one operating bands. A dual band normally supports both 900MHz and 1800MHz while a tri-band supports 900MHz, 1800MHz and 3G. The operating bands for these antennas are the downlink frequencies for the three bands used by the major mobile operators:

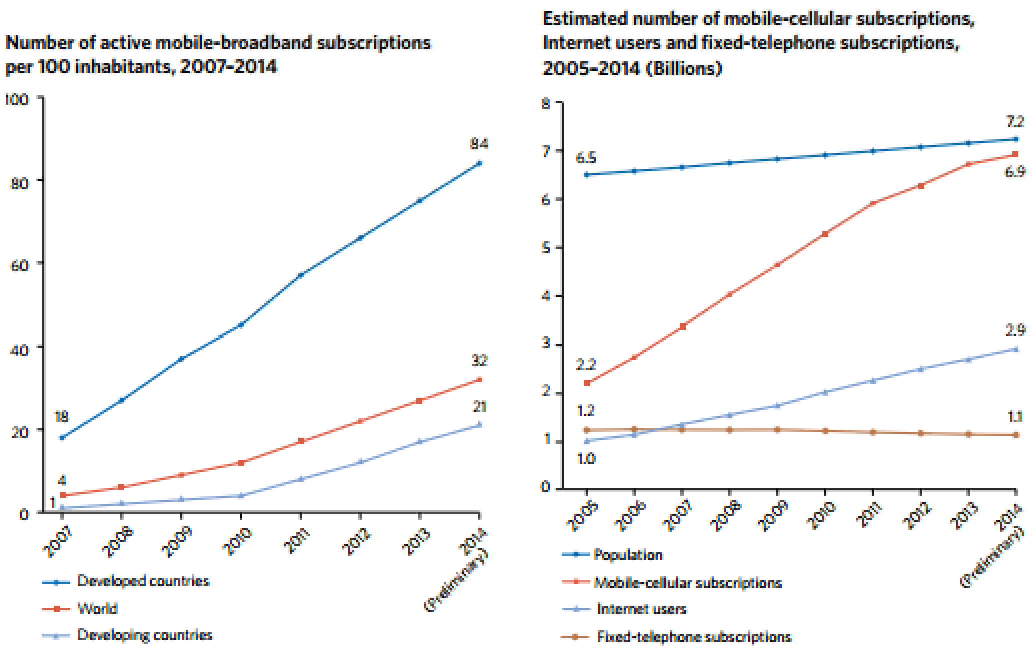
- GSM 900MHz (935-960 MHz)
- GSM 1800MHz (1805-1880 MHz)
- 2100 MHz (2110-2170 MHz) [3].

1.3 Problem statement

The ever expanding industry of telecommunications in this century has led to construction of mobile cellular towers at an exponential rate. The major reason still standing on the increase of cell phone users for both voice and data. This has been facilitated by introduction of GSM standards in the 1990s [5]. In Zimbabwe, cell phone users have increased mainly under the major mobile operators: Econet Wireless, Telecel and Netone who tallied at least 4603 base stations for 2G, 3G and LTE by 3rd quarter 2014. This has seen the internet penetration rate rising significantly from 37.3 % in June to 47.5% by September in 2014 alone [6].

The largest subscriber bases are mostly found to be highly populated areas such as residential areas, universities, urban cities, schools, sport grounds and other highly populated areas. Some mobile equipment is now found even on top of tall buildings which will reduce costs on mobile operators on the need to construct towers to achieve their much needed heights for transmission purposes. Mobile equipment is now a common feature in indoor places such as hotels and various other buildings especially those which have multiple floors. This is because communication is mostly poor in these buildings thus, operators opt to introduce Indoor building solutions (IBSs) for indoor coverages.

Almost three billion people are online and seven billion mobile-cellular subscriptions.



[7].

Figure 1.1 Mobile cellular and broadband penetration in recent years.

The main question now stands on whether this has impact on human life considering the nature of signals that are used for communication or whether the impact is negligible and not of concern or the impact is totally non-existent. If there is impact therefore the need to determine how far from the residential area should these base stations be constructed. This has created mixed feelings in the scientific world on the harmful effects of Electromagnetic radiation from these base stations [8]. The radiation from these base stations is considered low power but the main worry is on the continuity of the radiation [9].

With good health being a priority in day to day living of human beings, great fear has arisen as various reports from case studies reveal the various suspected biological and health effects of these radiations on humans. Such effects include breast cancer, brain tumour, headaches, nausea, to mention a few [5].

The need for communication will now seem overriding the need for good health if it is found that long term exposure to non-ionising radiation is harmful. The belief that EMR is only a worry at levels which cause a heating effect seem to be an underestimation and the majority of researches have proven that various stakeholders claim that the exposure limit standards in existence are far enough to guarantee their safety. This seems to relate to the tobacco industry which supressed science for long and no comprehensive precautions were taken against effects of smoking as smoking was said to be harmless until deception was unfolded [10]. With no conclusive evidence that the predefined levels of non-ionizing radiation affect the population, neither does evidence exist to prove that there are no effects when people are exposed to it for long periods [11]. This means therefore that this research is long awaited.

1.4 Generic research on the problem

The student has opted to simulate the radiation levels experienced by residences in the Emarald and Greencroft areas. Data from mobile companies will be used to model an exclusion zone from a mobile base station to an area of residence or house. The researcher expects this to raise awareness to all stakeholders on the radiation levels exposed to human life in the long run. With the Zimbabwean community currently not responding to the EMF radiation issues, this research will go a long way in raising relevant awareness.

1. 5 Aim of Study

The main aim of this project is to determine the proper distance (radius) that a mobile base station should be placed from an area of public residence that will not cause significant implications on human health in the long run.

1.5.1 Objectives

- To determine the electromagnetic radiation levels currently experienced by the public in places where mobile base stations are in the areas of residences.
- To determine the relationship between radiation levels and distance from mobile base station towers.
- To assess the validity of what is termed “safe radiation levels” according to international institutions such as ICNIRP, WHO in the Zimbabwean setup.
- To determine a safe distance margin (exclusion zone) that a base station should be placed from the area of residence (house) of the public such that radiation levels will be of insignificance impact in the long run.
- To strengthen the relationship between Mobile operators, the public and organisations dealing with safety issues concerning radiation emissions.
- To raise awareness on the need to minimise radiation.

1.6 Hypothesis

The research will produce a model for the minimum distance (radius) that a mobile base station should be placed from areas (house) of public residences. It will also give trends of variations of EMF radiation intensity levels with distance from transmitting elements.

1.7 Justification

The research will raise awareness on the level of EMF radiation intensities currently being experienced by the public. It will give mobile operators and involved stakeholders an insight of what needs to be put in place to ensure public safety from exposure to non-ionising radiation in the long run if the measured levels are found to be alarming. The research will also conscientise regulatory authorities on the need to regularly keep an eye on all activities that emit non-ionising radiation. The ongoing debate on non-ionising radiation level intensities will somewhat get a tangible reference information through this field based research.

Above all, the findings of this research will move to reduce the level of EMR intensity levels which the general public is exposed to as it intense to raise awareness on the current radiation levels.

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CHAPTER 2

THEORETICAL ASPECTS

2.1 Introduction

In this chapter, the researcher gives the necessary theoretical background in line with EMF radiation issues. Diagrams and tables have been included to clarify various important aspects. Mathematical equations used to calculate various important parameters are derived in this chapter and their significance shown.

2.2 Electromagnetic waves

An electromagnetic wave in a vacuum consists of mutually perpendicular and oscillating electric and magnetic fields. These fields are perpendicular to the direction in which the wave travels. It is a transverse wave. Electromagnetic waves propagate through a vacuum at the speed of light c(c = 3x108 ms^{-1}). This comes regardless of frequency. The frequency, wavelength, λ, and speed c, are related by the equation:

$$c = f\lambda \ldots\ldots\ldots\ldots(2.1)$$

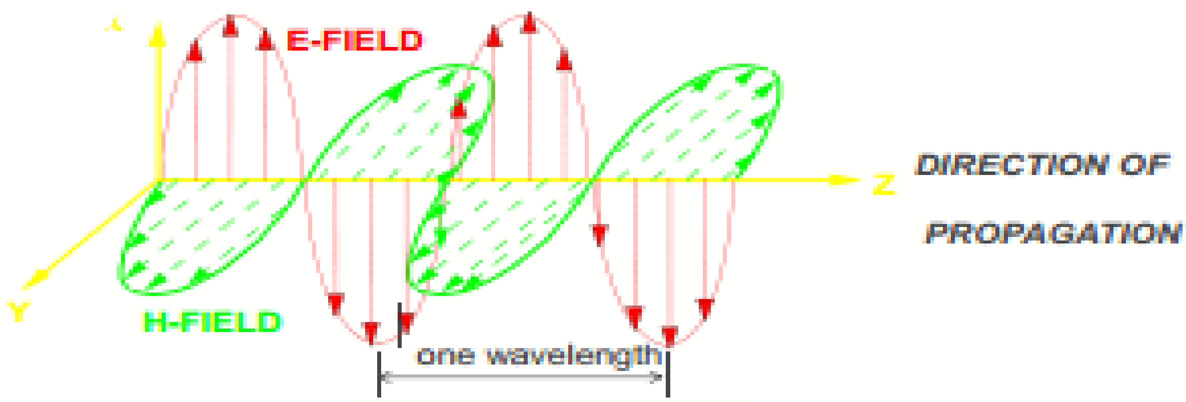

Figure 2.1 EM wave model [1].

2.2.1 EM Waves production

An electric field is produced by a charged particle. The electric field employs a force on other charged particles. Positive charges accelerate in the same direction with the field while negative charges accelerate the direction which is opposite to the direction of the field. A moving charged particle produces a magnetic field. The magnetic field employs a force on other the moving charges. Force on these charges is perpendicular to the direction of the velocity. This means therefore that what is the direction of the velocity and not that of the speed. Electromagnetic waves are produced by accelerated charged particles. These electromagnetic waves transport energy through space. The energy can be delivered to charged particles a large distance away from the source.

Accelerating charges produce changing electric and magnetic fields. Changing electric fields produce magnetic fields and changing magnetic fields produce electric fields. This interplay between induced electric and magnetic fields leads to propagating electromagnetic waves [2].

2.2.2 EM Waves propagation

EM wave propagation can be summed up as illustrated by below diagram, which shows the radiation profile and the magnetic and electric field components of a wave model.

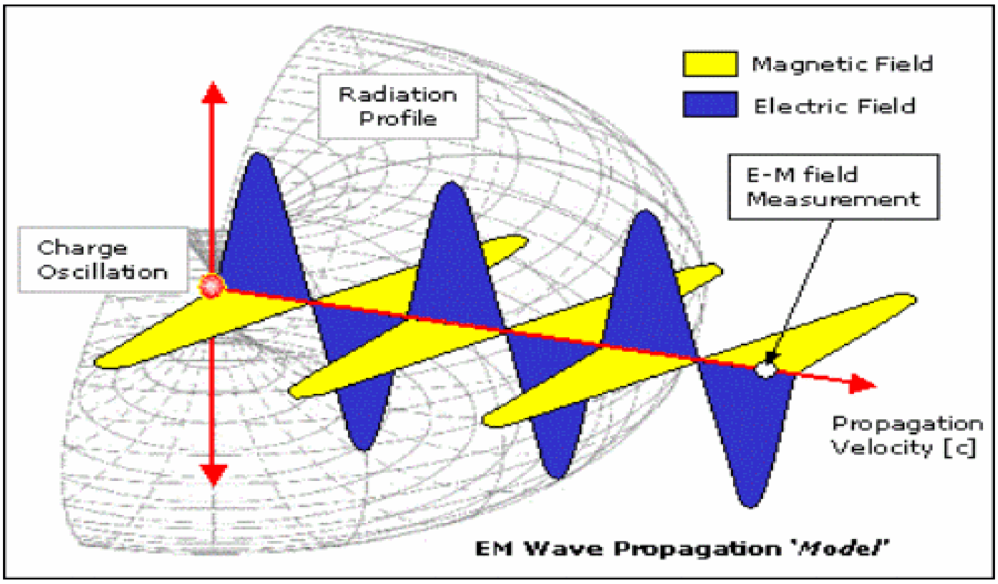

Figure 2.2 EM wave production [3].

These EM waves can be detected by making use of an antenna. The EM waves forces the charges in the antenna to oscillate which results in voltages being detected if a voltmeter was to be employed for measurement [4].

2.3 Electromagnetic Spectrum

The electromagnetic spectrum gives the distribution of electromagnetic waves in accordance to their energy, wavelength or frequency. This spectrum can be viewed as photons. These are particles which travel in a wave like pattern. They travel the speed of light given as $3x10^8$ ms^{-1} [5]. The above mentioned properties determine the ability of the radiation to travel through various objects, the heating effects capability and also the effects on living tissue. Below figure shows the spectrum layout:

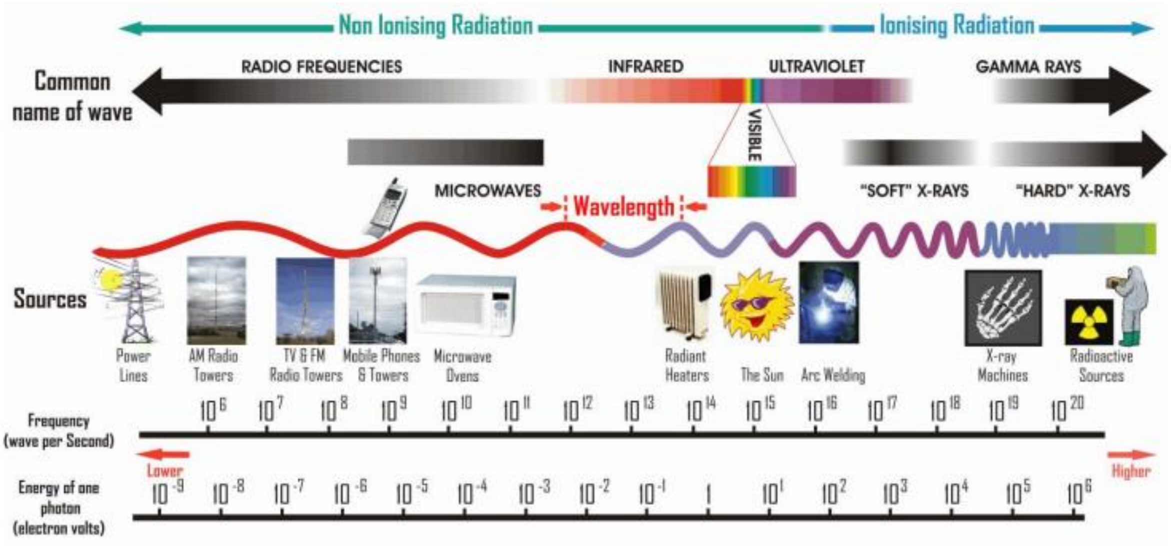

Figure 2.3 Electromagnetic spectrum [17].

Frequency is used to describe electromagnetic radiation. This can be considered as the number of cycles that an electromagnetic wave completes in 1 second. Wavelength is taken as the distance between two adjacent wave crests. Electromagnetic radiation travels at a constant speed of light. This means that frequency and wavelength are inversely proportional to each other, that is, a wave with higher frequency has a shorter wavelength and vice versa. This implies that when the wavelength increases, the frequency decreases. Frequency is measured in hertz, representing one wavelength per second. Wavelength in turn is measured in meters. The relationship between frequency and wavelength is given as in equation (2.1) above.

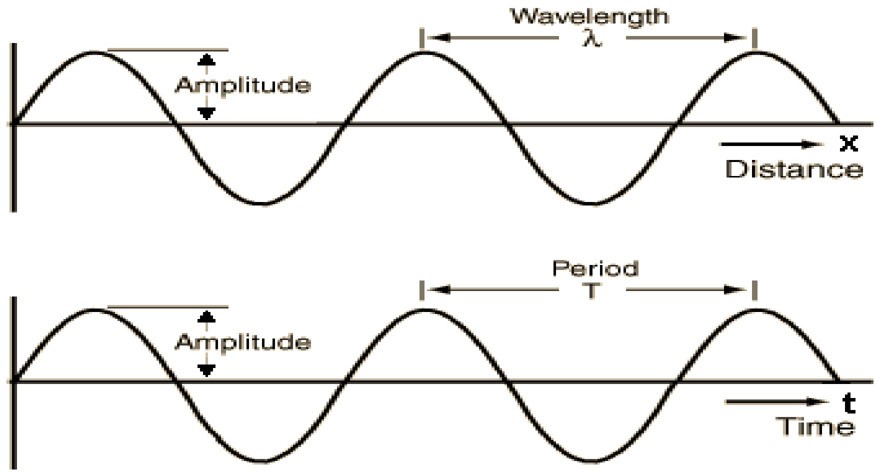

Figure 2.4 A simple waveform to show wavelength, frequency and amplitude [5].

2.4 Electromagnetic Field

The behaviour of electromagnetic field can be described by Maxwell's equations. Electromagnetic radiation consists of waves of electric and magnetic energy moving together through space at the speed of light. This term 'electromagnetic field' is also used to indicate the presence of electromagnetic radiation. Various forms of electromagnetic radiation are categorised by their frequencies. The term EMF is normally used to cover fields in the frequency ranges below 300 gigahertz (GHz). EMF comprises of electric and magnetic fields from the electricity supply, and radio waves from TV, radio and mobile phones, radar and satellite communications. Various home devices also transmit EMF. Such devices include cell phones and radio-controlled toys [18].

2.5 EMF Exposure and Health

The possibility of health effects emanating from these man-made sources have become an area of scientific interest. Electrical currents are essential in normal body operations. The nerve cells in the body relay their signals by transmitting electric impulses. Electrical processes are also involved in many biochemical reactions in the body. This include processes related to digestion and also those involved in brain activity. At low frequencies, EMF passes through the body. As the frequencies rise to radio frequencies, these fields become absorbed partially by the body, penetrating a short depth into the tissue [8]. At frequencies above 10GHz, the skin depth of absorption is very small. RF power at high frequencies is absorbed as surface heating, similar to heating from an infrared lamp. Exposure limit is based on incident power density.

Penetration to skin depth of 3.8 mm can be experienced for 10GHz and 0.36mm for 100GHz respectively [9]. Electric current can be caused to flow in the body when low-frequency electric fields influence the distribution of electric charges at the surface of conducting tissues. Magnetic fields at low frequencies in turn induce circulating currents within the human body. Induced current intensity will however depend on the intensity of the magnetic field and also the size of the loop through which the current flows. The induced currents can be large enough to stimulate nerves and muscles of the human body. At RF frequencies, the field can penetrate a small distance. The body tissue absorbs the energy of these fields and this energy is transformed into molecular movement. An increase in temperature can be effected by friction as a result of the movement of these molecules. The result will be an increase in temperature. The levels of RF fields in which people are daily exposed to are lower than the levels necessary to cause significant heating. This therefore continues to be a puzzle on trying to ascertain whether there are adverse health effects from such exposure or not. With the mobile technology too recent to nullify any possible harmful effects from RF exposure, conflicting research results continue to emerge at an alarming rate [8].

2.6 Near and far field Issues

In the near field region, the electric and the magnetic fields are not in phase, that is, E and H are out of phase. The field impedance is not constant and varies. The pattern of the antenna at this stage is still being formed. Simple formulas tend to overestimate exposure.

In the far field region, the electric and magnetic fields, E and H, are in phase. The impedance becomes constant at 377 Ohms (in free space). This is the region where the pattern of the antenna is fully formed. Simple formulas can be applied. Far-field strength can be estimated using the equation:

$$P_{\mathrm{d}} = \frac{PG}{4\pi d^2}\,(W/m^2) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2.2)$$

Where P= power into the antenna (W), G =Linear Isotropic gain, d= Distance from the antenna (m) [9].

The approximate near/far field boundary is defined as:

$$R = \frac{2L^2}{\lambda} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2.3)$$

Where R is the distance and L is the length of the antenna.

Table 2.1 Variation of the far field distance according to the frequency for GSM sources.

Frequency(MHz)	Far Field Distance
GSM (900 MHz)	6.4 (m)
GSM1800 (1800 MHz)	2.6 (m)

[10].

By using the above equation (2.3), the following results in table 2.2 were obtained by applying the centre frequency to find the wavelength of the band.

Table 2.2 Variation of the far field distance as calculated using the centre frequency for each band.

Band (MHz)	Upper frequency (MHz)	Lower frequency (MHz)	Centre frequency (MHz)	Antenna length (m)	Wavelength (m)	Near field boundary (m)
900	960	935	947.5	1.936	0.316622691	23.67547307
1800	1880	1805	1842.5	1.954	0.162822252	46.89919153
2100	2170	2110	2140	1.954	0.140186916	54.47178827

At a sufficiently large distance from the source, the electric and the magnetic field components are closely related. It becomes sufficient to evaluate each separately. This distance is as approximated by equation above, and so is expected to be greater than about $\frac{2L^2}{\lambda}$, where L the largest dimension of the antenna. λ is the wavelength. The exposure is normally characterised by the incident power density (W/m^2) as this is described as radiation. Electric and magnetic fields have a simple relationship and thus power density can be determined based on measurements of the electric field. This implies use of below equation:

$$S = \frac{E^2}{377} \dots\dots\dots\dots\dots\dots\dots\dots\dots..(2.4)$$

Where S is the power density (W/m^2) and E is the electric field (V/m).

The source can thus be approximated as a point source when in this far field region. This suggests a $\frac{1}{r^2}$ decrease and in the absence of interfering objects. Due to objects interfering the path, the decrease may be faster. It is thus difficult to make measurements in close vicinity of the base station. Calculations are also difficult due to the near filed conditions [11].

2.7 EMF Field Emissions from Telecom industry

Radiation from the telecom industry can be viewed from two main sources: emission from base transceiver stations (BTSs) which are mainly for GSM and 3G as well as 4G though CDMA is still to penetrate significantly in Zimbabwe since the major mobile operators are not employing it. Radiation also come from mobile handsets which have become a common mark in Zimbabwe. There are however other sources of emissions including radio and TV transmitters, and also from broadcast radios and various other sources not of concern to the scope of this research. Various factors are attributed to EMF radiation. These are:

- Operating power level for the transmitting element
- Operating frequency/wavelength of the RF signal being transmitted
- RF power radiated from the antenna
- Exposure time of RF signal for a given distance
- Age and size as well as portion of the body
- Humidity and temperature
- Duration/frequency of repeated exposure [12].

2.7.1 Radiation types

Radiation can be regarded as a form of energy on the move and is electromagnetic in nature. It can be classified as ionising and non-ionising depending on the energy levels of each [18].

2.7.1.1 Ionizing Radiation

Ionization can be regarded as the manner in which electrons are given the necessary energy to break away from their atoms. Ionizing radiation thus has higher energy levels compared to the non-ionizing spectrum. It has energy enough to effect chemical changes through chemical bond breaking which can cause tissue (living) damage. As the frequency on the magnetic spectrum increases to reach ultraviolet spectra, radiation strength begins to have the much needed energy for chemical bond breaking. With X-rays and gamma radiation at the top of the spectrum in terms of frequency, these have even higher frequencies and even shorter wavelengths. With the high energy levels possessed in this radiation range, electrons can be easily stripped from their atoms and at some energy levels atomic nuclei is broken up. Stripping of electrons thus cause electron deficit on atoms and create ions. Two ions therefore are generated in the process, that is, a molecule from which an electron has been stripped is left with a net positive charge, with the free electron standing as a negative charge. The ionization releases energy absorbed by the material surrounding the ionized atom.

Though other radiation types may release energy which is absorbed by the body, the amount of energy deposited by ionizing radiation is very high per unit area. Considering the carbon atoms which exist in body tissues, ionizing radiation has enough energy to disrupt the chemical bonds that exist between these carbon atoms. In simple terms, all ionizing radiation has the ability directly or indirectly to remove electrons from most of the molecules. The three main ionizing radiation types can be described as below:

Table 2.3 Ionizing radiation types

Radiation type	Description
Alpha particles	These include two protons and two neutrons and are not part of the electromagnetic spectrum, these are energetic particles as opposed to pure energy bundles (photons).
Beta particles	These are essentially electrons
Gamma rays and x-rays	These are pure energy(photons)

[6].

2.7.1.2 Non ionizing Radiation

This refers to the form of radiation that does not have the much needed energy to liberate electrons from their respective atoms or molecules. It comes mainly in the form of extremely low frequency (ELF), radio frequencies, microwave frequencies, lasers, infrared, visible spectrum and the ultra violet radiation when considering the order of increasing frequencies.

The spectrums mentioned above can be view as in Figure 2.3. The frequencies under the scope of this research fall in this category of non-ionising radiation.

2.7.2 Exposure From Base stations

Mobile phone base stations also known as Base transceiver stations or system can be regarded as radio transmitters that have antennae mounted at a height, which can be normally a tower mast or building. Radio wave signals are fed to the antennae at the tower mast through feeder cables which can be cylindrical wave guides normally and nowadays fibre has found its way for the use. The antennae at the mast would then radiate the radio signals into the sectorial area around it according to its mechanical and electrical properties.

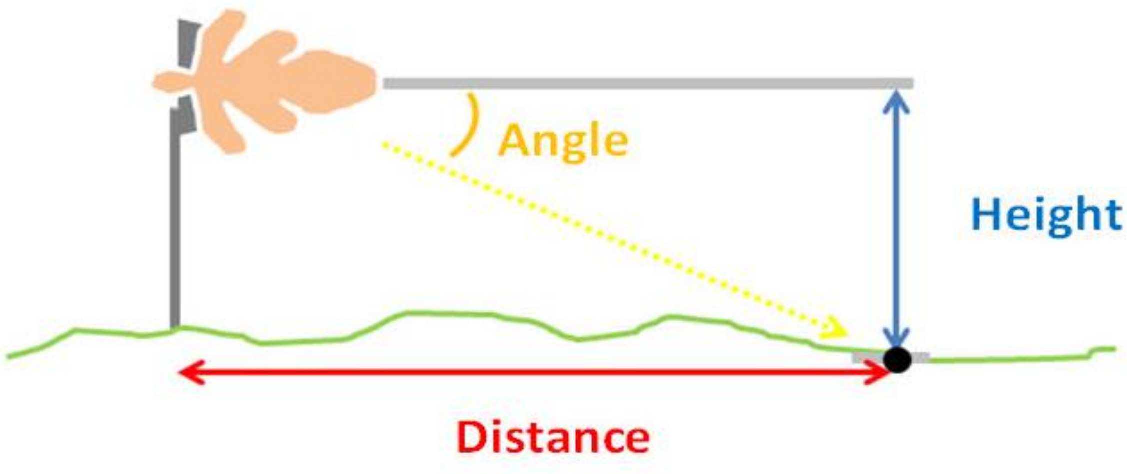

Figure 2.5 Model for GSM antenna mounted on a tower mast

$\text{Angle} = \arctan\left(\frac{h}{d}\right)$ … … … … … ..(2.5)

Where h =height and d = distance [13].

An antenna for GSM 900MHz transmits in the downlink frequency of 935 - 960 MHz. This is a 25 MHz band and is further slotted into twenty sub-bands of 1.2 MHz and assigned to mobile operators [14]. There may be several carrier frequencies (1 to 5) allotted to one operator with upper limit of 6.2 MHz bandwidth. Each may transmit 10 to 20W of power. This would mean that one operator may transmit 50 to 100W of power and 3-4 operators may share the same roof top or tower mast (through infrastructure sharing) and thus the total transmitted power would be 200-400W [15]. Also mobile operators make use of directional antennas which typically may be of gain 17dB. Radiated power density can be determined for N number of base stations at a given distance R_{n} using equation: [16].

$$P_{\mathrm{d}} = \sum_{n=1}^{N} \frac{P_{\mathrm{tn}} G_{\mathrm{tn}}}{4\pi {R_{\mathrm{n}}}^{2}} \dots \dots \dots \dots \dots \dots \dots (2.6)$$

Where P_{tn} =Transmitter power (W) from n^{th} station

G_{tn} =Gain of the transmitting antenna of n^{th} station

R_{n} =Distance from the transmitting antenna of n^{th} station in meters.

Using above steps, power density can be determined for the case of a single-carrier single-operator, that is, N=1 up to multiple carriers and multiple operators case.

Considering the case whereby there exist multiple operators under infrastructure sharing principle, this would mean the power densities would be increase several times compared to the single carrier single operator. Radiation density decreases as one moves away from the main beam of the antenna. This beam does not necessarily occur a few meters in front of the antenna but can be significantly incident to the ground several meters away depending on the degree of antenna tilting applied. The radiation exact radiation pattern of the antenna is necessary to calculate exact radiation density for a given point [17].

A typical radiation pattern is given below for typical antenna:

Figure 2.6 Typical Kathrein antenna [18].

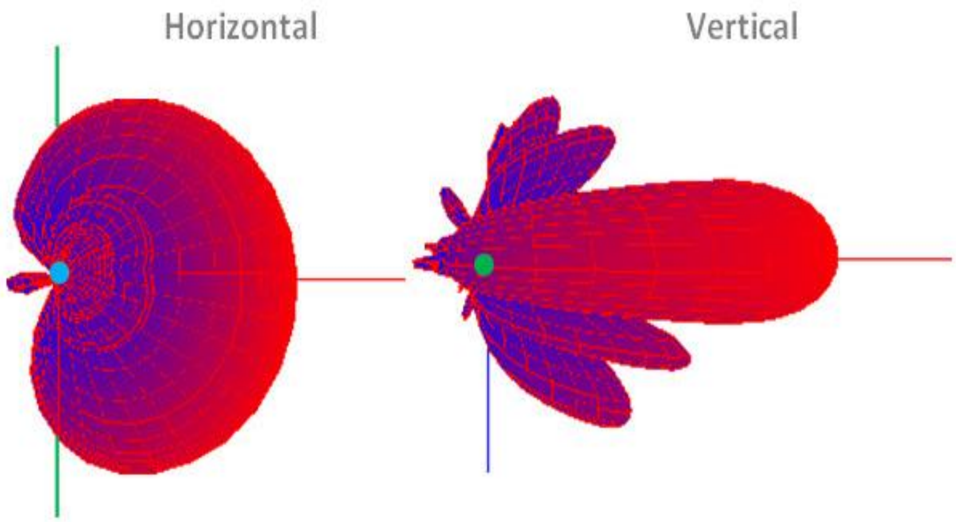

Figure 2.7 Typical radiation pattern for a Kathrein Antenna

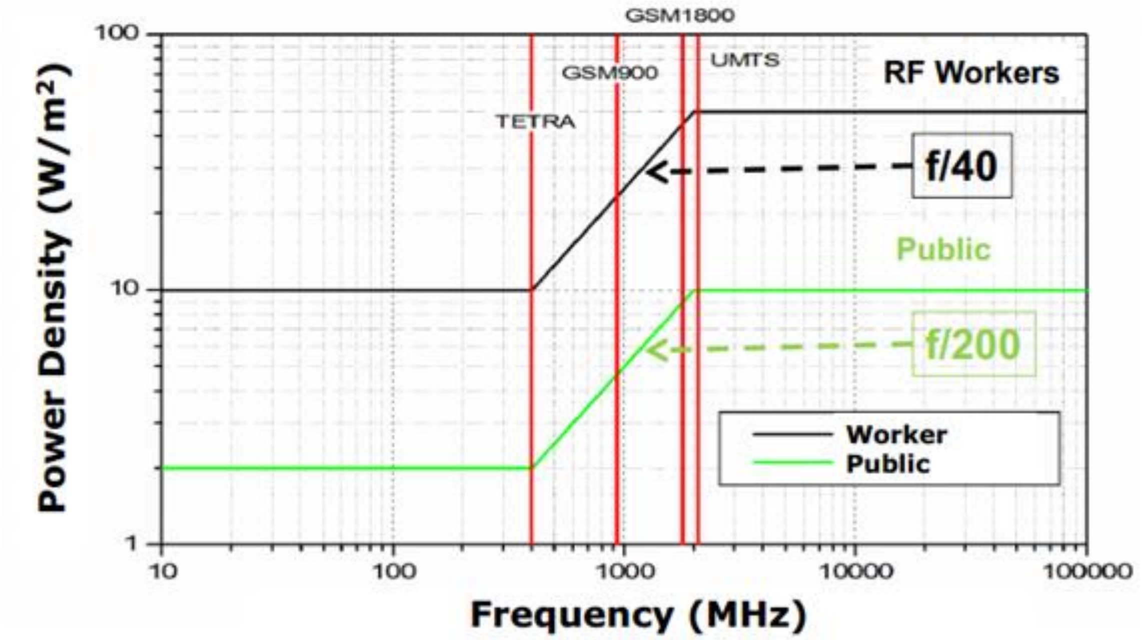

Figure 2.8 Compliance Limits for antennas [Reproduced with permision: License Number: 3630700671171 [19]]

2.7.3 Specific Absorption Rate (SAR)

This is the rate at which RF energy is absorbed by the human body over a given time per unit mass [20]. The following equation is used to calculate SAR:

$SAR = \frac{\sigma}{\rho} E^2 (W/kg)$………….. .(2.7)

$where\ \ \sigma = dielectric\ conductivity\ (Siemens/m - S/m)$

$\rho = tissue\ density\ (kg/m^3)$

and E = intermal Electric field strength (V/m)

Whole body SAR is affected by the intensity of the RF field and also the frequency of the RF field. Polarisation of the RF field also affects whole body SAR. The size of the person and the grounding of the person are also important in whole body SAR.

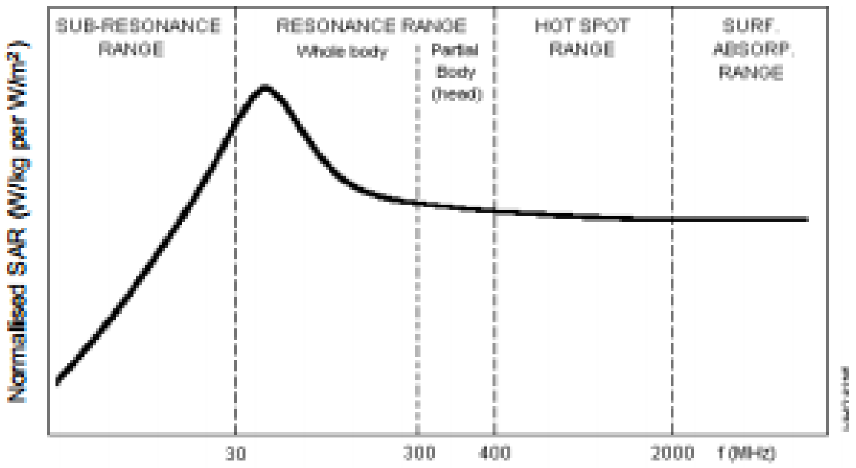

Figure 2.9 RF absorption versus frequency [9].

Table 2.4 SAR basic restrictions

Exposure Characteristic	Whole Body Averaged Specific Absorption Rate (W/kg)	Local SAR averaged over 10g of tissue	
		Head & Trunk	Limps (arms, legs)
Workers' Exposure	0.4	10	20
General Public Exposure	0.08	2	4

Basic restrictions =ICNIRP SAR Limits [19].

2.7.4 Radio Wave Propagation

2.7.5 Propagation mechanisms

Reflection: propagation wave impinges on an object which is large when comparing the size of the surface of the object with the wavelength of the radio wave. An example is the surface of the earth and walls of buildings.

Diffraction: This occurs when the transmission path between the transmitter and the receiver is obstructed by a surface which have sharp, irregular edges. Radio waves then bend round the obstacle even if there is no line of sight between the transmitter and the receiver.

Scattering: This occurs when there exist objects which are smaller when comparing with the wavelength of the radio wave under transmission. A common example is foliage [21].

2.7.6 Path Loss

This is a scenario which occurs when the received signal continue to decrease in terms of the received power levels due to increase in the distance between the mobile base station and the mobile station. This is also influenced by terrain contours, environment, that is, whether it's urban or rural, vegetation and foliage. Propagation medium also plays a part. Whether the propagation medium is moist air or dry plays a role. Also the separation distance between the transmitter and the receiver as well as the antenna height and location is a factor. The following equation defines path loss, L_p (free space).

$$L_p = \frac{P_t}{P_r} \quad (2.8)$$

Path loss in free space:

$$L_{pf(dB)} = 32.45 + 20log_{10}f_c(MHz) + 20log_{10}(km) \quad (2.9)$$

where fc is the carrier frequency.

This is valid only for land mobile systems which are close to the base station. The higher the frequency, the higher the attenuation.

2.8.3 Propagation models

Propagation models have been developed to estimate the radio wave propagation with high accuracy. The models try to cater for all propagation environments in order to obtain the path loss between the transmitting element and the receiving element. These estimate the necessary power levels required at the transmitter to give certain receive power levels at the receiver, which is in this case, a mobile station [22].

Propagation models have various characteristics. Path loss is the dominant factor. They also focus on path realization. Models predict the coverage area and the signal distribution representation. Different models exist for different types of radio links. Each model relies on the median path. The collection of data in any model has to be large enough to create likeness. These radio propagation models predict the most likely behaviour of a link rather than point out the exact behaviour of the radio link [21]. Propagation models come in three main types, that is, models for outdoor attenuations, models for indoor attenuations and models for environmental attenuations.

Table 2.5 Propagation models

Model Type	Class	Examples	
Models for Outdoor Attenuations	Near Earth propagation Models	Foliage Model	Weissberger's MED Model
			Early ITU Model
			Updated ITU Model(One Woodland Terminal Model, Single Vegetative Obstruction Model)
		Terrain Model	Egli Model
			ITU Terrain Model
		City Model	Young Model
			Okumura Model
			Hata Model For Urban Areas
			Hata Model For Suburban Areas
			Hata Model For Open Areas
			Cost 231 Model
			Area to Area Lee Model
			Point to Point Lee Model
Models for Indoor Attenuations	ITU Model For Indoor Attenuations		

	Log distance Path Loss Model		
Models for Environmental Attenuations	Rain Attenuation Model	ITU Rain Attenuation Model	
		ITU Rain Attenuation model for Satellites	
		Crane Global Model	
		Crane Two Component Model	
		Crane Model For Satellite Paths	
		DAH Model	

The complexity of any given propagation model affects its applicability and accuracy. The major models (in terms of usage) come in the form of the Okumura and Hata models [22].

2.8.3.1 Okumura-Hata Model

This is mainly used for large cells. Large cells are used in rural areas where subscribers are sparsely spread and thus, high power is used for transmission to cater for distance which becomes a more pronounced factor than capacity. Sub rural also have these large cells since subscribers are not close together due to the settlement patterns employed [22].

This is the most commonly used model. It can be used up to 3GHz. Distance between the transmitter and the receiver can be up to 100km. The receiver height can be 3m to 10m [23].

2.8.3.2 Okumura Model

This is mainly used for signal prediction in the urban environment setup. It is used for frequencies ranging from 150 MHz up to 1920 MHz. It can be extrapolated up to 3GHz. It can cater for distances ranging from 1km up to 100 km for base station heights of 30m up to 1000m. This model is based on measured data and does not provide any analytical explanation. It gives a high accuracy path loss prediction for mature cellular and land mobile radio systems in cluttered environment. The path loss equation is given below:

$$L_{50}(dB) = L_F + A_{mu}(f, d) - G(h_{te}) - G(h_{re}) - G_{AREA} \quad \ldots\ldots\ldots\ldots\ldots(2.10)$$

where:

L_{50}= percentile value or median value.

L_F = free space propagation loss.

A_{mu}= median attenuation relative to free space.

$G(h_{te})$= base station antenna height gain factor.

$G(h_{re})$ =mobile antenna height gain factor.

G_{AREA} = gain due to the type of environment.

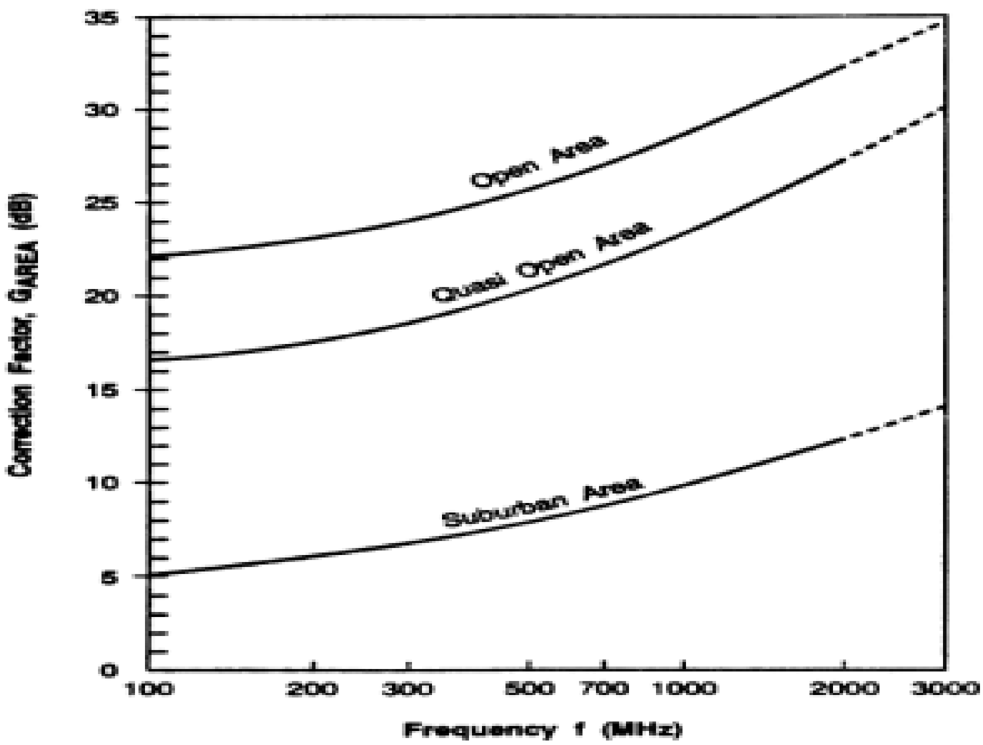

Figure 2.10 Correction factor, G_{AREA},for different types of terrain [21].

2.8.3.3 Hata Model Urban Areas

This is the most widely used model in Radio frequency. Used for predicting the behaviour of cellular communication in built up areas. It is also applicable to the transmission inside cities. It is also suitable for point to point and broadcast transmission. The operating frequencies for this model range from 150 MHz to 1.5 GHz. The transmission height is normally up to 200m and sustaining link distances less than 20km. The path loss equation:

$L_U = 69.55 + 26.16 \log f - 13.82 log h_B - C_H + [44.9 - 6.55 log h_B] log d$ ………..…(2.11)

For small or medium seized city, the following equation applies:

$C_H = 0.8 + (1.1 \log f - 0.7) h_M - 1.56 \log f$ ……………..…(2.12)

For large cities, the following applies:

$C_H = \{8.29(log(1.54h_M))^2 - 1.1, if\ 150 \leq f \leq 200)$ ……..(2.13)

$$and\ \{3.2(log(11.75h_M))^2 - 4.97, if\ 200 < f \leq 1500)$$

Where $C_H = correction\ factor\ for\ effective\ antenna\ height.$

2.8.3.4 Hata Model for Suburban Areas

This is for predicting cellular transmission behaviour in city outskirts and other rural areas. The model is applicable for transmission just out of the cities and rural areas. It works where there exist man-made structures but these structures should not be high for this model to be valid. Modelling frequency ranges are from 150MHz up to 1.5 GHz. The path loss equation for suburban areas is given as below:

$L_{SU} = L_U - 2\left(log\frac{f}{28}\right)^2 - 5.4$ ………(2.14)

where:

$L_{SU} = path\ loss\ in\ suburban\ areas$ $L_U = average\ path\ loss\ in\ urban\ areas, in\ dB$ and $f = transmission\ frequency, in\ MHz$

2.8.3.5 Hata Model For Open Areas

This model is used for predicting cellular transmission behaviour in open areas, where no obstructions block the transmission link. It is there froe suitable for point-to-point and broadcast links. The model is valid for frequency ranges of 150 MHz up to 1.5 GHz. The path loss equation for the model is given as below:

$L_O = L_U - 4.78(logf)^2 + 18.33logf - 40.97$ ……………(2.15)

$L_O = path\ loss\ in\ open\ areas, in\ dB$,$L_U = path\ loss\ in\ urban\ areas, in\ dB$ and *f* = transmission frequency, in MHz [21].

2.9 ICNIRP background

ICNIRP comes as an independent scientific board that emanated as a successor to IRPA/INIRC in May 1992 at the Eighth International Congress of the IRPA. This board endeavours to investigate the associated hazards from different NIR (Non Ionising radiation) forms. It gives a framework for reducing EMF exposure that will ensure protection of people and animals against known adverse health effects. Adverse health effects cause noticeable impairment of the health of the exposed individual or of his or her offspring; a biological effect, on the other hand, may or may not result in an adverse health effect. In 1988, IRPA gave guidelines on the high frequency and the 50/60 Hz electromagnetic fields and INIRC also did the same in 1990.The now present guidelines supplanted the above guidelines which stands to span its frequency coverage range for time varying EMF (up to 300GHz), with the issued 1994 ICNIRP framework covering up the static magnetic fields [24].

2.9.1 ICNIRP Roles

The ICNIRP commission undertakes to:

- draw up international guidelines on limiting exposure to non-ionizing radiation that are independent and science based
- give guidance and the much needed advice on health hazards of non-ionizing radiation
- providing science based guidance and recommendations on protection from non-ionizing radiation exposure.

2.9.2 ICNIRP Guidelines

The commission drafts its guidelines basing on a two-level protection system, that is, basic restrictions and reference levels [24]. Below flow chart models the steps involved when the ICNIRP is developing its guidelines [25].

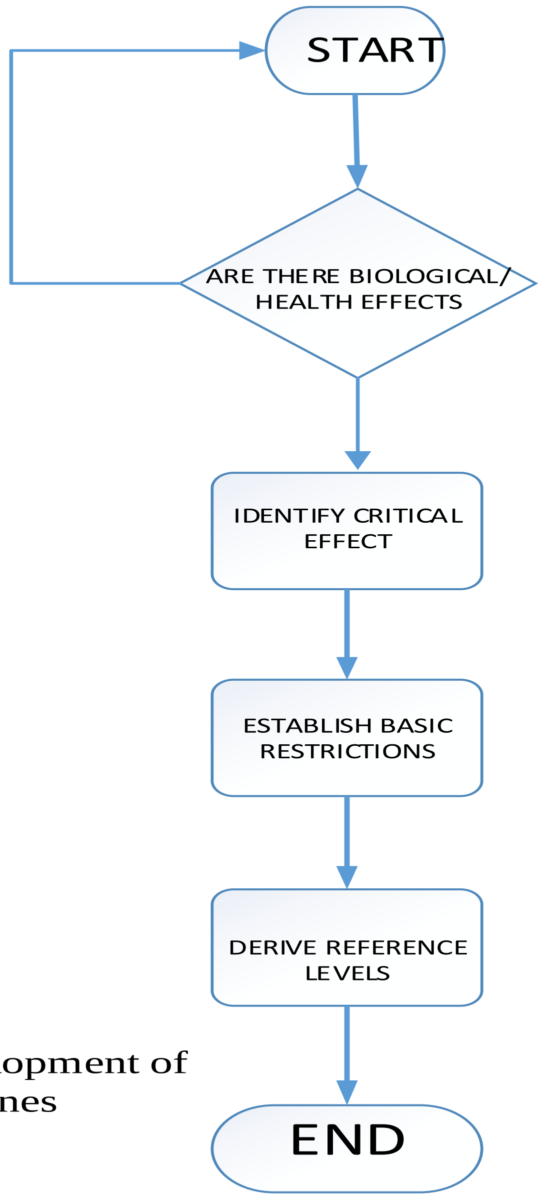

Fig 2.11 Development of Guidelines

For critical established effect, the following criteria should be met:

- Adverse or at least disturbing
- Relation to exposure clear and consistent
- Plausible physical and biological mechanism
- Repeatable, not based on a single study

Scientifically established effects adverse or disturbing effects of time varying EM-fields are based on:

- Heating of tissue, including thermos-elastic transients
- Electrical stimulation of nerve cells and related effects on neural networks
- Electroporation of cell membranes
- Spark discharges and surface effects [26].

2.9.3 Basic restrictions

These are restrictions on exposure to time-varying electric, magnetic, and electromagnetic fields that are based directly on established health effects. Depending upon the frequency of the field, the physical quantities used to specify these restrictions are current density (J), specific energy absorption rate (SAR), and power density (S). Only power density in air, outside the body, can be readily measured in exposed individuals [24].

Table 2.6 ICNIRP Basic restrictions-SAR

Type of Exposure	Frequency range	Whole-body average SAR (W/kg)	Localised SAR (head and trunk) (w/kg)	Localized SAR (limbs)(W/kg)
Occupational	100kHz-10MHz	0.4	10	20
	100MHz-10GHz	0.4	10	20
General Public	100kHz-10MHz	0.08	2	4
	100MHz-10GHz	0.08	2	4
NB: f-frequency in Hertz All SAR values to be averaged over any 6-minute period The localized SAR averaging mass is any 10g of contiguous tissue; the maximum SAR so obtained should be the available used for the estimation of exposure.				

[24].

Table 2.7 Basic restrictions for power densities between 10 and 300 GHz.

Exposure Characteristics	Power Density (W m^{-2})
Occupational Exposure	50
General Public	10

Note:

Power densities are to be averaged over any 20cm2 of exposed area and any 68/f1.05-minute period (with f in GHz) to compensate for progressively shorter penetration depth as the frequency increases.

Spatial maximum power densities, averaged over 1 cm2 should not exceed 20 times the values above [24].

2.9.4 Reference levels

These levels are provided for practical exposure assessment purposes to determine whether the basic restrictions are likely to be exceeded. Some reference levels are derived from relevant basic restrictions using measurement and or using computational techniques, and some address perception and adverse indirect effects of exposure to EMF. The derived quantities are electric field strength (E), magnetic field strength (H), magnetic flux density (B), power density (S), and currents flowing through the limps (I_L). Quantities that address perception and other indirect effects are contact current (I_C) and for pulsed fields, specific energy absorption (SA). In any particular exposure situation, measured or calculated values of any of these quantities can be compared with the appropriate reference level. Compliance with the reference level will ensure compliance with the relevant basic restrictions. If the measured or the calculated value exceeds the reference level, this does not necessarily follow that the basic restriction will be exceeded. However when a reference level has been exceeded, it is necessary to test the compliance with the relevant basic restriction and to determine whether additional protective measures are necessary [24].

2.10 Exposure Assessment

This research is focused on determining the safe distance margin from a cellular mobile base station such that the radiated EMF (Electromagnetic Magnetic Field) will not be harmful to humans who stay close to the base station in the long run. EMF intensity measurements are going to be made to determine EMF radiation intensity levels that are currently experienced by humans in places where mobile base station towers have been built in their areas of residences.

Table 2.8 Basic restrictions 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 (W kg^{-1})	Localized SAR (head and trunk) (W kg^{-1})	Localized SAR (limbs) (W kg^{-1})
Occupational Exposure	Up to 1Hz	40	-	-	-
	1-4 Hz	40/f	-	-	-
	4 Hz-1kHz	10	-	-	-
	1-100kHz	f/100	-	-	-
	100kHz-10MHZ	f/100	0.4	10	20
	10MHZ-10GHz	-	0.4	10	20
General public exposure	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	0.08	2	4
	10 MHz-10 GHz	-	0.08	2	4

Note**:**

- f is the frequency in hertz
- Because of electrical inhomogeneity of the body, current density values should be averaged over a cross-section of 1 cm^2 perpendicular to the current direction.
- For frequencies up to 100 kHz, peak current density values can be obtained by multiplying the rms value by √2(~1.414). For pulses of duration t_p the equivalent frequency to apply in the basic restrictions should be calculated as f =1/(2t_p).
- For frequencies up to 100 kHz and for pulsed magnetic fields, the maximum current density associated with the pulses can be calculated from the rise/fall times and the maximum rate of change of magnetic flux density. The induced current density can then be compared with the appropriate basic restriction.
- All SAR values are to be averaged over any 6-min period.
- Localized SAR averaging mass is any 10 g of contiguous tissue; the maximum SAR so obtained should be the value used for the estimation of exposure.
- For pulses of duration t_p the equivalent frequency to apply in the basic restrictions should be calculated as f=1/ (2 t_p). Additionally, for pulsed exposures in the frequency range 0.3 to 10 GHz and for localized exposure of the head, in order to limit or avoid auditory effects caused by thermoelastic expansion, an additional basic restriction is

recommended. This is that the SA should not exceed 10mJ kg^{-1} for workers and 2mJ kg^{-1} for the general public averaged over 10g tissue [24].

Table 2.9 Reference levels for occupational exposure to time-varying electric and magnetic fields (unperturbed rms values**)**

Frequency range	E-field strength (V m^{-1})	H-field strength (A m^{-1})	B-field (μT)	Equivalent plane wave power density S_{eq} (W m^{-2})
Up to 1 Hz	-	1.63 x 10^5	2 x10^5	-
1-8 Hz	20 000	1.63 x 10^5 /f^2	2 x10^5/f^2	-
8-25 Hz	20 000	2 x10^4/f	2 x10^4/f	-
0.025-0.82kHz	500/f	20/f	25/f	-
0.82-65kHz	610	24.4	30.7	-
0.065-1MHz	610	1.6/f	2.0/f	-
1-10MHz	610/f	1.6/f	2.0/f	-
10-400MHz	61	0.16	0.2	10
400-2000MHz	3$f^{1/2}$	0.008$f^{1/2}$	0.01$f^{1/2}$	f/40
2-300GHz	137	0.36	0.45	50

[24].

Note:

- f as indicated I the frequency range column
- Provided that basic restrictions are met and adverse indirect effects can be excluded, field strength values can be exceeded.
- For frequencies between 100 kHz and 10 GHz, S_{eq}, E^2, H^2, and B^2 are to be averaged over any 6-min period
- For frequencies exceeding 10 GHz, S_{eq}, E^2, H^2, and B^2 are to be averaged over any 68/f $_{1.05}$
- -min period (f in GHz).
- No E-field value is provided for frequencies,1Hz, which are effectively static electric fields. Electric shock from low impedance sources is prevented by established electrical safety procedures for such equipment.

Table 2.10 Reference levels for general public exposure to time-varying electric and magnetic fields (unperturbed rms values)

Frequency range	E-field strength (V m^{-1})	H-field strength (A m^{-1})	B-field (μT)	Equivalent plane wave power density S_{eq} (W m^{-2})
Up to 1 Hz	-	3.2×10^4	4×10^4	-
1-8 Hz	10 000	$3.2 \times 10^4 / f^2$	$4 \times 10^4 / f^2$	-
8-25 Hz	10 000	4000/f	5000/f	-
0.025-0.8kHz	250/f	4/f	5/f	-
0.8-3kHz	250/f	5	6.25	-
3-150kHz	87	5	6.25	-
0.15-1MHz	87	0.73/f	0.92/f	-
1-10MHz	$87/f^{1/2}$	0.73/f	0.92/f	-
10-400MHz	28	0.073	0.92	2
400-2000MHz	$1.375f^{1/2}$	$0.0037f^{1/2}$	$0.0046f^{1/2}$	f/200
2-300GHz	61	0.16	0.20	10

Note:

- f as indicated in the frequency range column.
- Provided that basic restrictions are met and adverse indirect effects can be excluded, field strength values can be exceeded.
- For frequencies between 100 kHz and 10 GHz, S_{eq}, E^2, H^2, and B^2 are to be averaged over any 6-min period.
- Between 100 kHz and 10 MHz, peak values for the field strengths are obtained by interpolation from the 1.5-fold peak at 100 kHz to the 32-fold peak at 10 MHz. For frequencies exceeding 10 MHz it is suggested that the peak equivalent plane wave power density, as averaged over the pulse width does not exceed 1,000 times the S_{eq} restrictions, or that the field strength does not exceed 32 times the field strength exposure levels given in the table.
- For frequencies exceeding 10 GHz, S_{eq}, E^2, H^2, and B^2 are to be averaged over any $68/f^{1.05}$-min period (f in GHz).
- No E-field value is provided for frequencies, 1 Hz, which are effectively static electric fields. Perception of surface electric charges will not occur at field strengths less than 25 kVm^{-1}. Spark discharges causing stress or annoyance should be avoided [24].

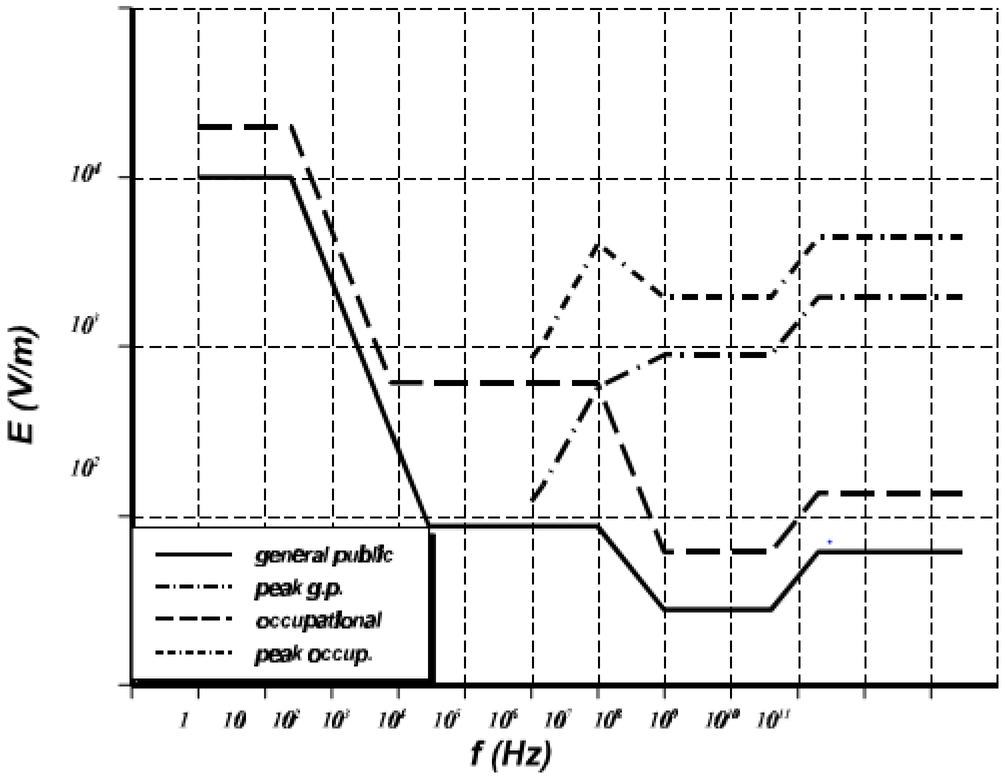

Figure 2.12 Reference level for exposure to time varying electrical field [Reproduced with permision: License Number: 3630700671171 [19]]

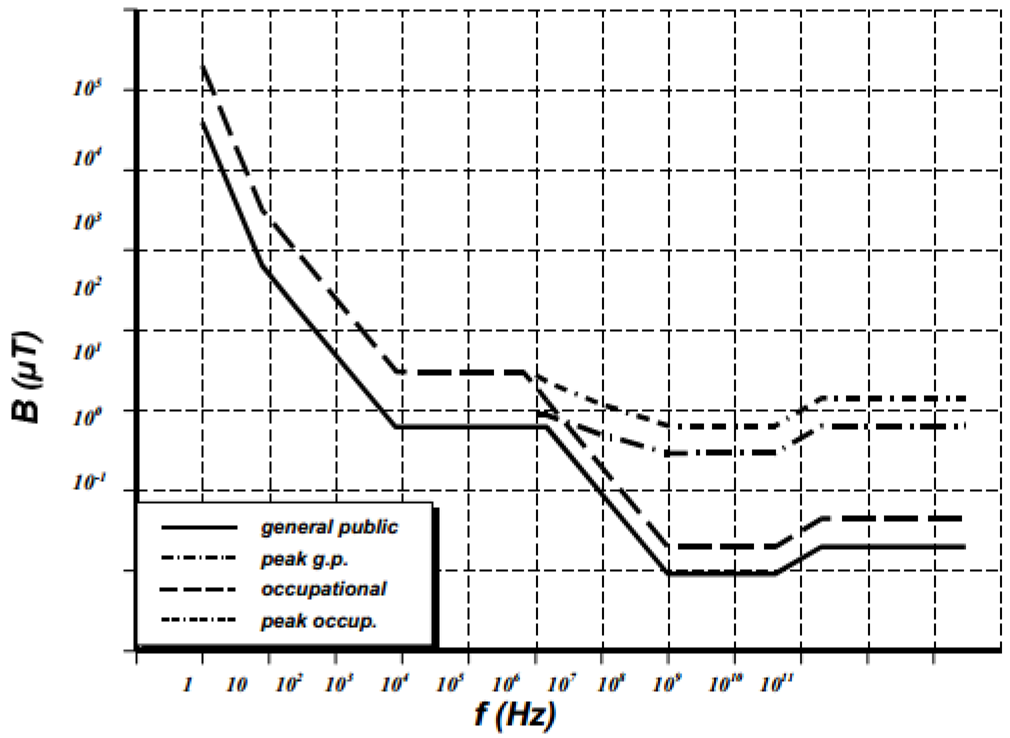

Figure 2.13 Reference level for exposure to time-varying magnetic field [Reproduced with permision: License Number: 3630700671171 [19]]

ICNIRP guidelines have been adopted for use by various organisations including the International Telecommunications Union (ITU) and also the World Health Organisation (WHO). Zimbabwe is also operating under ICNIRP guidelines. This therefore means that the Radiation Protection Authority of Zimbabwe (RPAZ) and POTRAZ have all adopted the ICNIRP guidelines for use in the Zimbabwean setup.

2.11 Model Equations derivation

Power density is going to be derived as received at destination in free space for the far field region by applying the free space equation. Consider radiation emission from a single cellular base station.

Figure 2.14 35m Mobile tower base station at St Georges in Emarald Hill area, near The Chase Note: All bands available as evidenced by presence of dual band antennas at top (900 +1800Mhz) and 2100 (3G) at the bottom on single band antennas].

The following diagram is key in deriving below concepts.

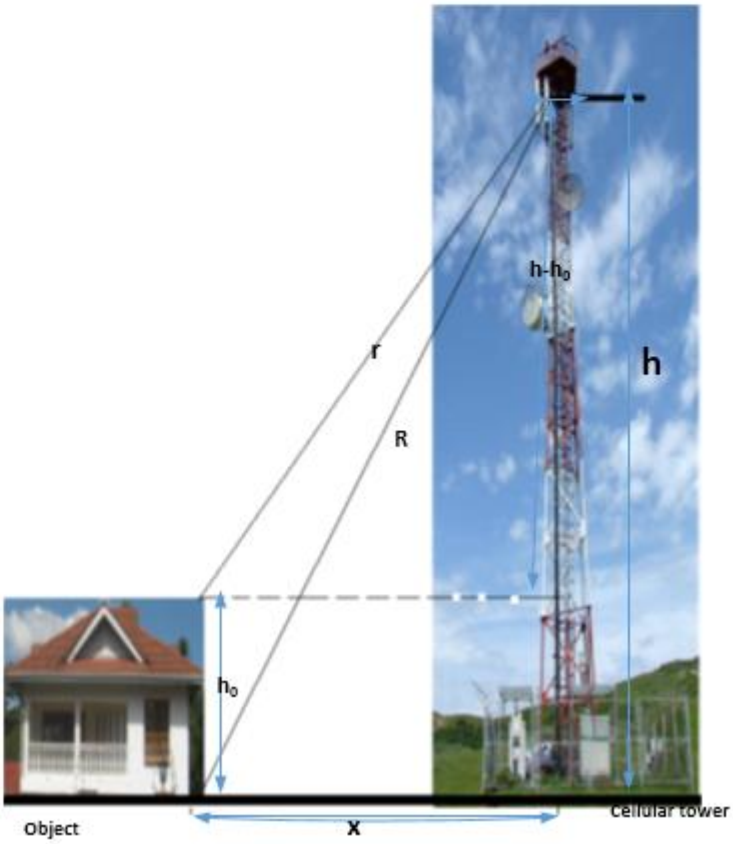

Figure 2.15 Model for exposure to a single source

The power density at point on the ground at a distance, x metres from the tower is given by the equation:

$P_{\mathrm{d}} = \frac{P_{\mathrm{t}}G_{\mathrm{t}}}{4\pi R^2}$ ……………………………………………….(2.16)

Where Pd is the power density from the cellular tower in Wm^{-2}

$R^2 = x^2 + h^2$ …..(2.2) …………………………………….(2.17)

And thus we have:

$P_{\mathrm{d}} = \frac{P_{\mathrm{t}}G_{\mathrm{t}}}{4\pi(x^2+h^2)}$……………………………………………..(2.18)

$P_{\mathrm{d}} = \frac{P_{\mathrm{t}}G_{\mathrm{t}}}{4\pi r^2}$…………………………………………………..(2.19)

$r^2 = x^2 + (h - h_0)^2$…………………………………………(2.20)

This implies that:

$$P_{\mathrm{d}} = \frac{P_{\mathrm{t}}G_{\mathrm{t}}}{4\pi[x^2+(h-h_0)^2)]} \qquad \text{...(2.21)}$$

Now consider an object of height h_0, to compute the total power density absorbed by the object, integration (calculus) can be employed and also show that the total power density can be calculated as:

Total power density:

$$\int_0^{h_0} P_{\mathrm{d}} = \frac{P_{\mathrm{t}}G_{\mathrm{t}}}{4\pi}\left[\arctan\left(\frac{h}{x}\right) - \arctan\left(\frac{h-h_0}{x}\right)\right] \qquad \text{....................(2.22)}$$

Consider two EMF sources from two towers.

Figure 2.16 Two cellular base stations in proximity near Greencroft Shops, Harare, Zimbabwe.

A model representation of the above scenario is as below (Consider the base stations as tower1 and tower 2):

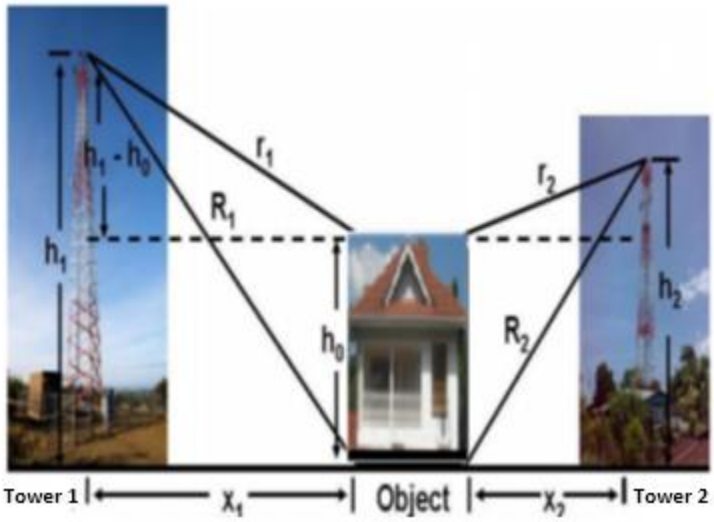

Figure 2.17 Model for exposure to two sources simultaneously

$R_1{}^2 = h_1{}^2 + x_1{}^2$………………………………………(2.23)

and

$R_2{}^2 = h_2{}^2 + x_2{}^2$………………………………………(2.24)

but

$P_{\mathrm{d},1} = \frac{P_1 G_1}{4\pi R_1{}^2}$……………………………………………(2.25)

$P_{\mathrm{d},2} = \frac{P_2 G_2}{4\pi R_2{}^2}$……………………………………………(2.26)

Substituting for (2.24) and (2.23):

$P_{\mathrm{d},1} = \frac{P_1 G_1}{4\pi(h_1{}^2 + x_1{}^2)}$……………………………………...(2.27)

$P_{\mathrm{d},2} = \frac{P_2 G_2}{4\pi(h_2{}^2 + x_2{}^2)}$………...…………………………....…..(2.28)

Combining (2.27) and (2.28) we have:

$P_{\mathrm{d}} = P_{\mathrm{d},1} + P_{\mathrm{d},2} = \frac{1}{4\pi}\left[\left(\frac{P_1 G_1}{(h_1{}^2 + x_1{}^2)}\right) + \left(\frac{P_2 G_2}{(h_2{}^2 + x_2{}^2)}\right)\right]$…………(2.29)

and

$P_{\mathrm{d}} = P_{\mathrm{d},1} + P_{\mathrm{d},2} = \frac{1}{4\pi}\left[\left(\frac{P_1 G_1}{(h_1 - h_0)^2 + x_1{}^2}\right) + \left(\frac{P_2 G_2}{(h_2 - h_0)^2 + x_2{}^2}\right)\right]$…...(2.30)

Considering a number of towers n, applying the above concepts, this implies that:

$$P_{\mathrm{d,i}} = \sum_{i=1}^{n} \frac{P_{\mathrm{i}} G_{\mathrm{i}}}{4\pi R_{\mathrm{i}}^{2}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2.31)$$

for

$$R_{\mathrm{i}}^{2} = x_{\mathrm{i}}^{2} + h_{\mathrm{i}}^{2} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2.32)$$

This implies that:

$$P_{\mathrm{d,i}} = \sum_{i=1}^{n} \frac{P_{\mathrm{i}} G_{\mathrm{i}}}{4\pi (x_{\mathrm{i}}^{2} + h_{\mathrm{i}}^{2})} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2.33)$$

If height of object h_0 is considered:

$$P_{\mathrm{d,i}} = \sum_{i=1}^{n} \frac{P_{\mathrm{i}} G_{\mathrm{i}}}{4\pi [x_{\mathrm{i}}^{2} + (h_{\mathrm{i}} - h_{0})^{2}]} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2.34)$$

$$P_{\mathrm{d,i}} = \frac{1}{4\pi} \sum_{i=1}^{n} \left[\frac{P_{\mathrm{i}} G_{\mathrm{i}}}{[x_{\mathrm{i}}^{2} + (h_{\mathrm{i}} - h_{0})^{2}]} \right] \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2.35)$$

[27].

2.11.1 EMF power density variation with distance

Basing on the power density equations above, by varying transmitted power levels from 50-100 watts, the following typical graphs can be obtained for various antenna gains in the range of 2-15dB as indicated on graphs. 100 watts in this case has been assumed to be the maximum transmitted power and 15dB as the maximum antenna gain.

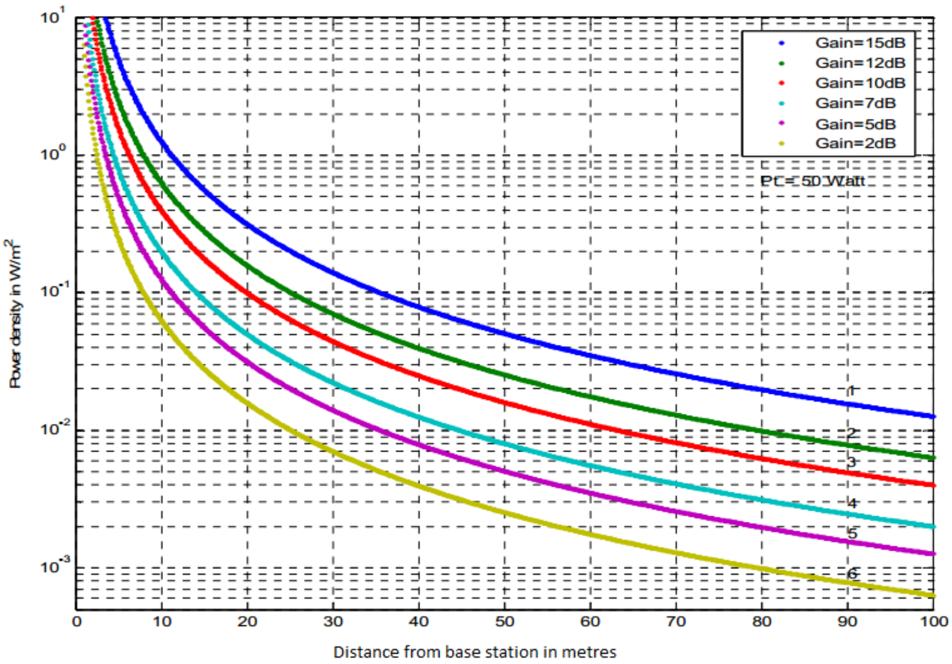

Figure 2.18 Typical calculated power density vs distance variation for Pt = 50watts

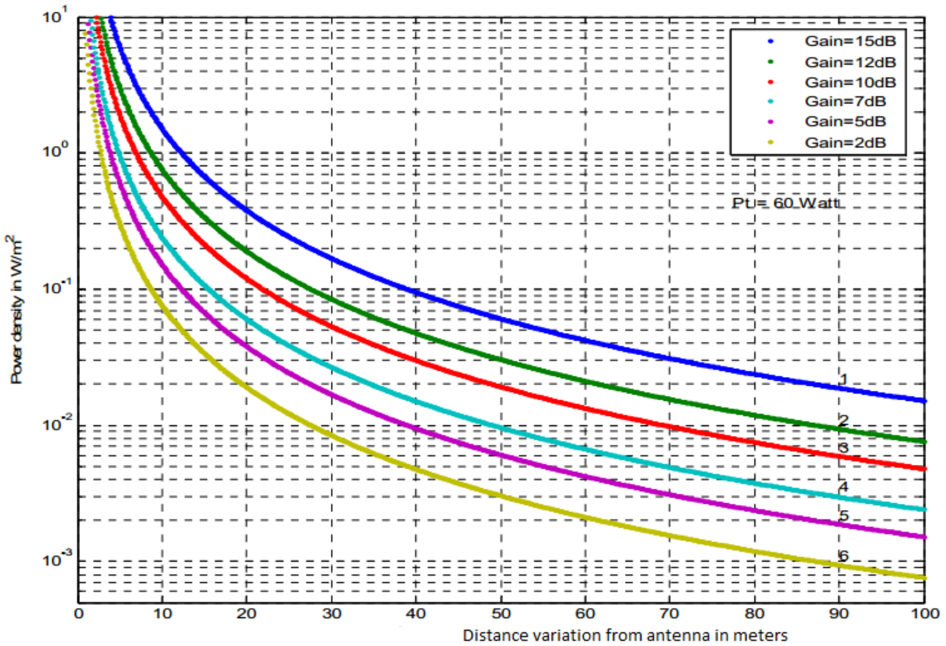

Figure 2.19 Typical calculated power density vs distance variation for Pt = 60watts

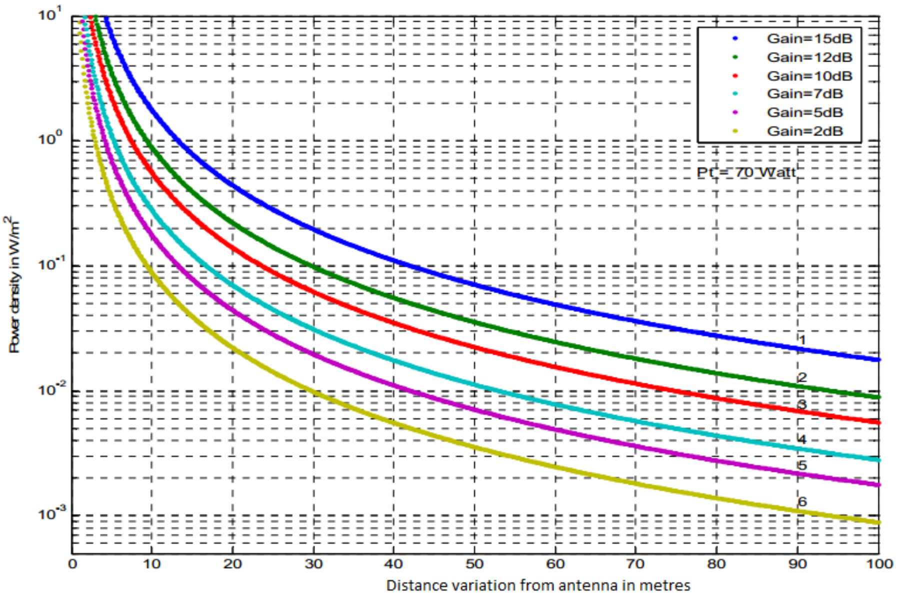

Figure 2.20 Typical calculated power density vs distance variation for Pt = 70watts

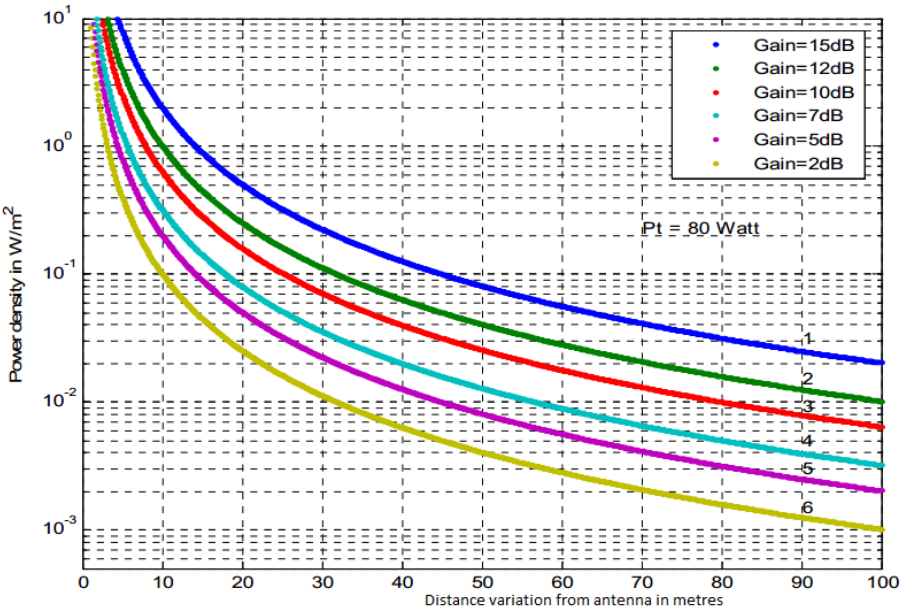

Figure 2.21 Typical calculated power density vs distance variation for Pt = 80watts

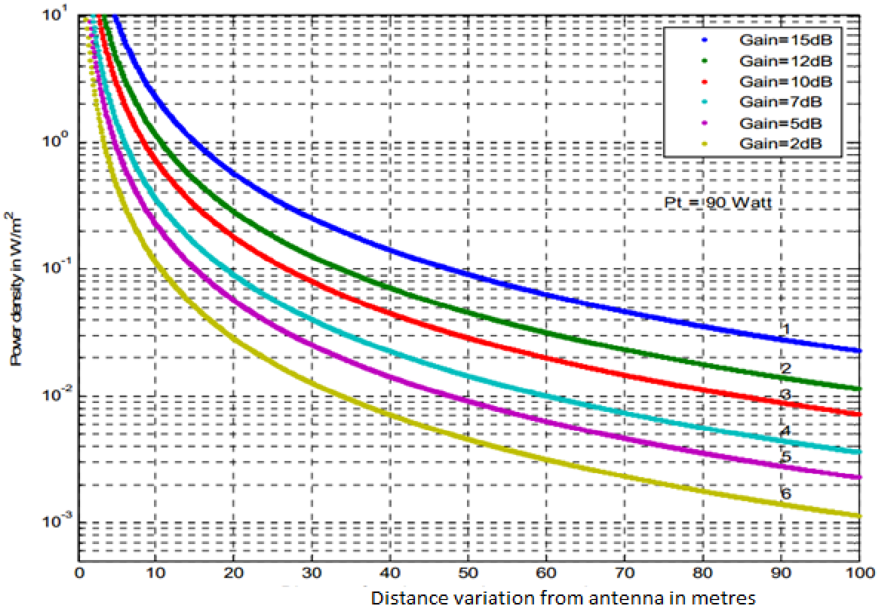

Figure 2.22 Typical calculated power density vs distance variation for Pt = 90watts

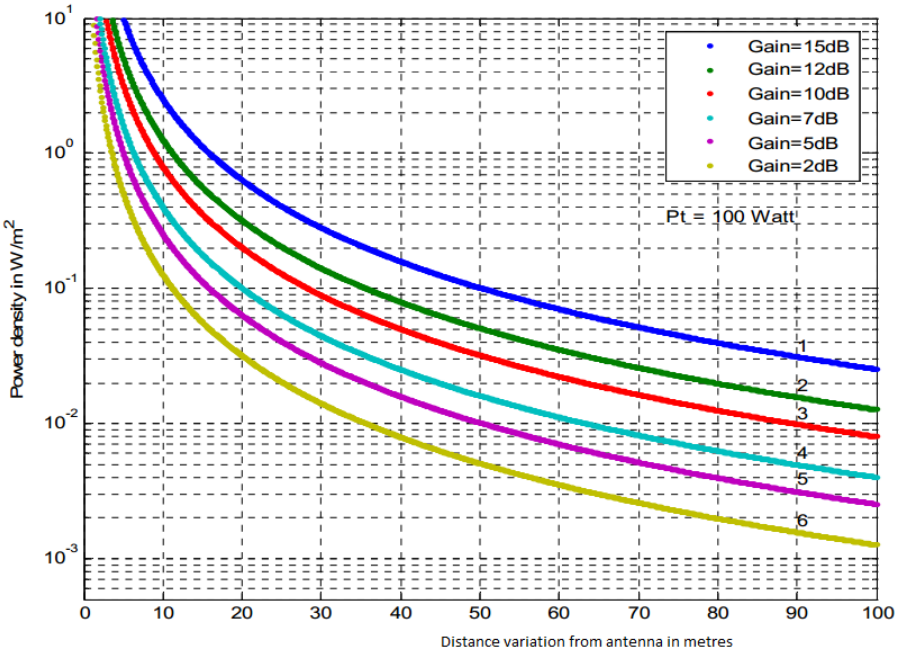

Figure 2.23 Typical calculated power density vs distance variation for Pt = 100watts [28].

2.11.2 Field (Wave) Impedance

The field (wave) impedance, Z, is the ratio of the electric (E) to the magnetic (H) field strength.

This is expressed in below equation:

$Z = \frac{E}{H}$ … … … … … … … … … … ….……………………………….(2.36)

Where E is in Volts/metre (V/m)

H in Amperes/metre (A/m)

Z=377 Ω in free space in the far field.

2.11.3 Power Flux density

This can be the rate of electromagnetic energy flow across a unit area. The relationship between E, H and S in the far field can be summed up by below equations:

$S = E \; x \; H \; (W/m^2)$ … … … … … … … … … … … … … … . . (2.37)

$S = \frac{E^2}{377} \; (W/m^2)$ … … … … … … … … … … … … … … …(2.38)

$S = 377 \; x \; H^2 \; (W/m^2)$ … … … … … … … … … … … … … ..(2.39)

$E = \sqrt{S * 377} \; (V/m)$ … … … … … … … … … … … … … … ..(2.40)

Where E= Electric field strength; H = Magnetic field strength; S =Power flux density [1].

2.11.4 Compliance distance calculation

Considering 900MHz, compliance distance can be calculated as below assuming 20W power per carrier, and gain of 16dB for the antenna:

Power into the antenna =43dbm =20W

Antenna gain =16dBi =40

Limit at 900 MHz for the public

=900/200

=4.5Wm^{-2}

$d = \frac{\sqrt{PG}}{4\pi S} \; (m)$…………………………………..(2.41)

$$d = \frac{\sqrt{20 * 40}}{4\pi * 4.5}$$

$= 3.8m$ [9].

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CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter gives an overview on the detailed procedures and assumptions that the researcher used to achieve the objectives defined in the first chapter. The justification for each step is given herein. Diagrams have also been included to add clarity for each principle applied by the researcher.

3.2 Justification of the area of study

With so many areas of residences relevant for assessment including Gweru residences in which the researcher is well versed in and stays, the researcher however had to choose Emarald Hills and Greencroft areas for the purpose of study due to a number of issues. Firstly, the source of measuring equipment was POTRAZ, which is in the Emarald Hills area. Considering the delicacy nature of the measuring equipment to be used (SMP tool), doing measurements in nearby places would reduce the risk of equipment damage by reducing the mileage. The total mileage necessary for the measurements was approximately 10km to reach all the chosen base stations.

Logistical costs would also be minimised by choosing an area near the source of measuring equipment comparing to any other area of residence near POTRAZ premises. Considering the scope of the research which intended to do measurements for all frequency bands used by major mobile operators, mobile base stations found in the area of study have all these bands at almost all sites. All mobile operators have their base stations in this area which would enhance a better credibility to results obtained.

The base station density in the area of study also was enough to attract attention of the researcher. Since the researcher wanted to experience cases for single source (base station) exposure and also multi source scenarios, this need could be met by the distribution of the base station in the area of study.

Figure 3.1 Photograph showing two mobile base stations in proximity, Greencroft, Harare, Zimbabwe.

Figure 3.2 Photographs showing two base stations in proximity in Emarald hills area, near The Chase Highway, Harare, Zimbabwe.

3.2 Identifying frequency bands available on base stations

The researcher had to visit the base stations physically to identify the bands at each site. By looking at the size of the antenna and based on the experience acquired by the researcher in the telecoms field, the researcher could easily identify the bands available by looking at the physical size of the antennas. Since 900MHz has the largest wavelength for the three bands understudy, its antenna is expected to be the largest and that of the 2100MHz to be the smallest. This was the case for single band antennas. However, most of the antennas are dual bands and tri-bands. These have electrical tilt knobs beneath them and by counting the number of knobs, and also that the number of these corresponds to the number of bands.

Figure 3.3 Mobile base station with 3G (2100MHz) antennas at the bottom and dual band (900MHz and 1800MHz) at the top.

3.3 Parameters used

The researcher used data from mobile companies and also from equipment vendors. From the mobile companies, information gathered include tower height, antenna type, and antenna gain and transmit power. Antenna gain and transmit power was necessary to enhance calculation of received power density levels for various points from the tower. Also the frequency bands under use were obtained from mobile operators and confirmed by POTRAZ. Antenna parameters from mobile companies also matched data sheets from vendors datasheets downloaded online. The minimum tower height was provided as 25m and maximum tower height as 45m for all base stations in the study area.

The main parameters of concern to be obtained from the simulations is power density, $P_{d,}$ and Electric field strength. Equations and models from chapter 2 have been employed to determine the above mentioned parameters. The researcher considered the worst case scenario in achieving the outlined objectives and thus, maximum transmit power per carrier was considered as for the modelling and the band producing the highest levels was considered for modelling the multi-source scenario cases for exposure to more than one sources. From the data obtained from the mobile operators, the Kathrein antennas were considered for use as these would give a better worst case scenario for the simulation. The key parameters obtained for maximum transmit power and gain are as given in table below.

Table 3.1 Parameters of the antenna and tower mast commonly used in the area of study for 1800MHz and 2100MHz.

Tower Height	25m		
Antenna Type	Kathrein 741 327		
Antenna Frequency Range(MHz)	870-1880		
Antenna Height (m)	22		
Antenna Length(m)	1.936		
Antenna Frequency Band (MHz)	Gain (dBi)	+45° and -45° polarization horizontal beamwidth	+45° and -45° polarization vertical beamwidth
870-960	17 =50.1187233627272W*	65	9.5
1710-1880	18.5	60	5.5
Transmit Power (W)	25		

Note: Transmit power is as configured by mobile operator and depends on the performance of the Remote Radio Unit (RRU) connected to the antenna and the licencing terms of the operator.

Table 3.2 Parameters for antenna commonly used for 900MHz in the area of study.

Tower Height	25m		
Antenna Type	Kathrein 742 213V01		

Antenna Frequency Range(MHz)	1710-2200		
Antenna Height (m)	20		
Antenna Length(m)	1.954		
Antenna Frequency Band (MHz)	Gain (dBi)	+45° and -45° polarization horizontal beamwidth	+45° and -45° polarization vertical beamwidth
1710-1880	19=79.43282347W*	67	4.7
1850-1990	19.2	65	4.5
1920-2200	19.5=89.12509381W*	63	4.3
Transmit Power (W)	25		
Tower Height (m)	25		

Note: Gains of interest and use in this research are indicated with (*)

[1].

3.4 Simulation justification

In line with the objectives in the first chapter, a well-informed simulation using first hand data comes as the best alternative to measuring considering the inconveniences that emanated from the measuring procedure using the SMP tool. Also ICNIRP and various other bodies of high credibility managed to use this method opted by the researcher to give the current guidelines for EMF exposure and thus, this validates the credibility of simulating EMF issues as done by the researcher in the next chapter.

3.4.1Simulation Procedure

Using the models in chapter 2, parameters were first entered in Microsoft excel where formulae were entered to calculate various parameters. Obtained results were entered into matlab software for actual simulation. Excel was chosen because of its easiness in calculations considering the nature of calculations that were being done and its ability to give a high level of accuracy to several decimal places before rounding off calculated figures. Matlab was used for its efficiency as an engineering tool. It gives models and graphs at very high accuracy and precision and the output can be modified at ease to suit the type of displays needed according to purpose of simulation [2].

Below is a snippet from excel showing some of the calculations done.

Pt (W)	Gt(19dBi=79.43	X (m)	h (m)	h_0 (m)	h-h_0 (m	h^2 (m2)	X^2	$(h-h_0)^2$	R (m)	r (m)	P_d (W/m^2)	E(V/m)
25	89.12509381	5	22.977	4	18.977	527.9425	25	360.1265	552.9425	385.1265	0.460390877	13.1745

Figure 3.4 Snippet from excel showing the parameters used for the single source scenario.

Pd(W/m2) was determined by inputting the formula:

=((A2*B2))/(((4*3.1415926535898)*(H2+I2)))

And E(V/m) by entering the formula:

=SQRT(L2*377) for single source scenarios.

For multiple sources scenario, a different worksheet was used where relevant formulae were entered and parameters varied accordingly. A snippet is given below.

Pt(W)	Gt(19.5d	X_1 (m)	X_2 (m)	h_1 (m)	h_2(m)	h_0 (m)	h_1-h_0 (m	h_2-h_0 (m	h_1^2 (m2)	h_2^2 (m2)	X_1^2	X_2^2	$(h_1-h_0)^2$	$(h_2-h_0)^2$	R_1(m)	R_2(m)	r_1 (m)	r_2 (m)	P_{d1} (W/n	P_{d2} (W/n	P_d (W/m^2)	E_T(V/m)
25	89.1251	5	95	22.977	22.977	4	18.977	18.977	527.9425	527.9425	25	9025	360.1265	360.1265	552.9425	9552.943	385.1265	9385.127	0.460391	0.018893	0.4792834	13.442092

Figure 3.5 Snippet from excel showing the parameters used for the two sources scenario.

P_d(W/m2) was calculated by entering the formula:

=SUM(T2,U2)

Where T2 and U2 are Pd_1(W/m2) and Pd_2(W/m2) respectively and obtained from formulae:

=(A2*B2)/((4*3.1415926535898)*(N2+L2))and
=(A2*B2)/((4*3.1415926535898)*(O2+M2)) respectively, with E_T(V/m) obtained by entering formula: =SQRT(V2*377) where V2 is P_d (W/m^2).

Using these formulae and other relevant ones for other parameters as on the models in chapter 2, tables were produced as given in the next chapter.

The relevant columns data was input into matlab for simulation. An example for a software algorithm used to produce below output from matlab is given in appendix A

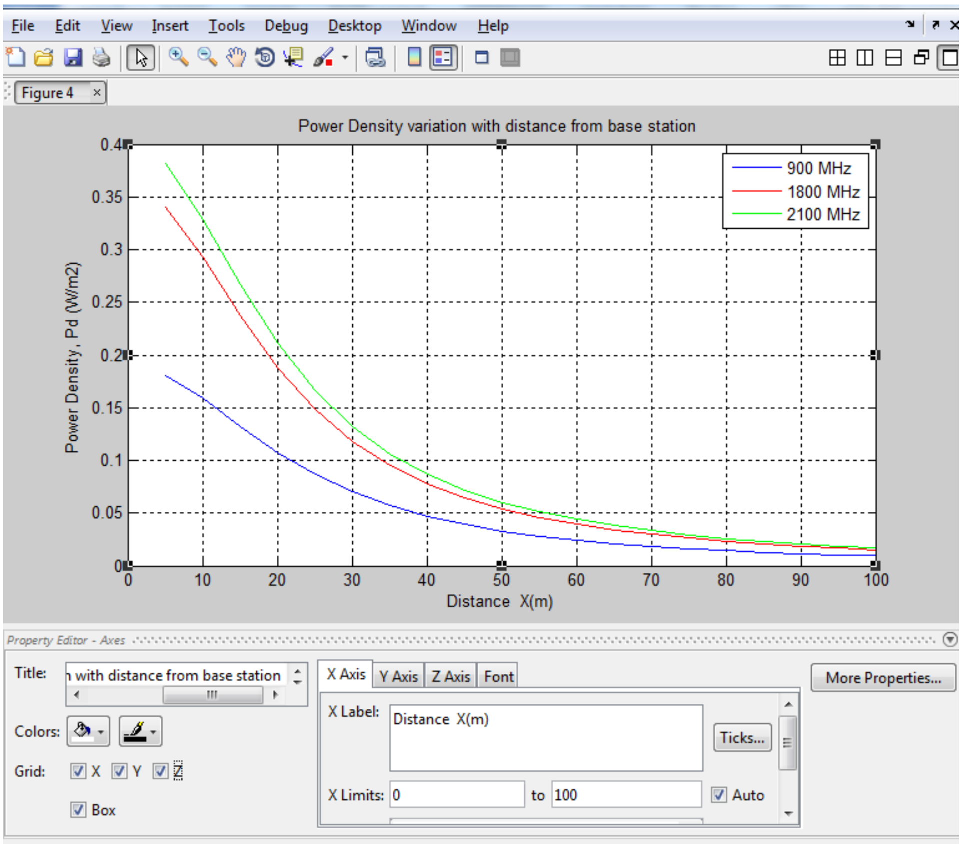

Figure 3.6 Output from matlab when the above input is used.

Using above procedure, the power densities and electric fields for various scenarios were modelled up and the results are as in the next chapter. The simulation was also done taking an initial distance of 5m and not 0m. This is the near field region and reactive region where even measurements are difficult to consider credible. The magnetic and electric field are not yet fully formed and also the presence of massive metallic objects in the form of the tower and the fencing itself also would mean that the simulation equations applied by the researcher do not hold for the near field since these assume far field region.

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CHAPTER 4

RESULTS AND ANALYSIS

4.1 Introduction

This chapter serves to give a thorough analysis and scrutiny on the findings of the research. Graphs have been included to give a better view of the findings as well as readability purposes. Relevant photos have also been included to show a clear picture of the scenarios that are the major subject of this research. Scenarios included here are limited to the three bands under consideration as indicated in chapter 1.

4.2 Single source modelling

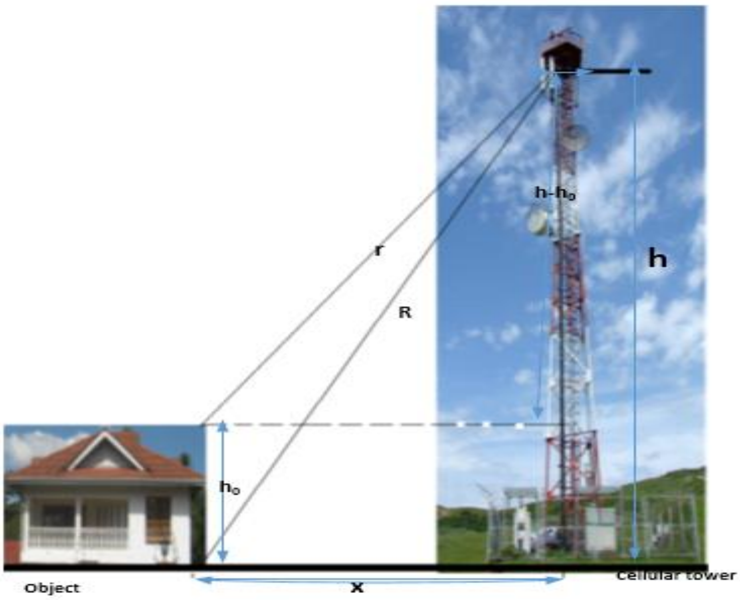

Figure 5.1 Model to simulate single source scenario.

Applying the equations from chapter 2:

$P_{\mathrm{d}} = \frac{P_{\mathrm{t}}G_{\mathrm{t}}}{4\pi[x^2+(h-h_0)^2)]}$ …………………..(2.21) and E =√S*377………….(2.40)

Case1: Assume h_0=0m and x=5-100m

Note: h =antenna height + ½(antenna length)

=22 + ½(1.936)

=22+0.968

=22.968m. (h is height to the middle of the antenna unlike antenna height).

Table 5.1 Power densities and Electric fields obtained for 900MHz

X (m)	**h (m)**	**$(h-h_0)$ (m)**	**h^2 (m^2)**	**X^2 (m^2)**	**$(h-h_0)^2$ (m^2)**	**R (m)**	**r (m)**	**P_d (W/m^2)**	**E(V/m)**
5	22.968	22.968	527.529	25	527.529	552.529	552.529	0.180457547	8.248181
10	22.968	22.968	527.529	100	527.529	627.529	627.529	0.158889913	7.739606
15	22.968	22.968	527.529	225	527.529	752.529	752.529	0.132497258	7.067635
20	22.968	22.968	527.529	400	527.529	927.529	927.529	0.107498557	6.366079
25	22.968	22.968	527.529	625	527.529	1152.529	1152.529	0.086512383	5.710969
30	22.968	22.968	527.529	900	527.529	1427.529	1427.529	0.069846588	5.131487
35	22.968	22.968	527.529	1225	527.529	1752.529	1752.529	0.056893798	4.631302
40	22.968	22.968	527.529	1600	527.529	2127.529	2127.529	0.046865651	4.203374
45	22.968	22.968	527.529	2025	527.529	2552.529	2552.529	0.039062448	3.837518
50	22.968	22.968	527.529	2500	527.529	3027.529	3027.529	0.032933799	3.52364
55	22.968	22.968	527.529	3025	527.529	3552.529	3552.529	0.028066775	3.252872
60	22.968	22.968	527.529	3600	527.529	4127.529	4127.529	0.024156834	3.017802
65	22.968	22.968	527.529	4225	527.529	4752.529	4752.529	0.020979994	2.812376
70	22.968	22.968	527.529	4900	527.529	5427.529	5427.529	0.018370797	2.63169
75	22.968	22.968	527.529	5625	527.529	6152.529	6152.529	0.016206024	2.471775
80	22.968	22.968	527.529	6400	527.529	6927.529	6927.529	0.014393015	2.329413
85	22.968	22.968	527.529	7225	527.529	7752.529	7752.529	0.012861356	2.201983
90	22.968	22.968	527.529	8100	527.529	8627.529	8627.529	0.011556963	2.087337
95	22.968	22.968	527.529	9025	527.529	9552.529	9552.529	0.010437867	1.983703
100	22.968	22.968	527.529	10000	527.529	10527.53	10527.53	0.009471171	1.889612

Note: h =antenna height + ½(antenna length)

=20 + ½(1.954)

=20+0.977

=20.977m. (h is height to the middle of the antenna unlike antenna height)

Table 5.2 Power densities and electric fields obtained for 1800MHz

X (m)	**h (m)**	**$h-h_0$ (m)**	**h^2 (m^2)**	**X^2 (m^2)**	**$(h-h_0)^2$**	**R (m)**	**r (m)**	**P_d (W/m^2)**	**E(V/m)**
5	20.977	20.977	440.0345	25	440.0345	465.0345	465.0345	0.339816877	11.31861
10	20.977	20.977	440.0345	100	440.0345	540.0345	540.0345	0.292623106	10.50328
15	20.977	20.977	440.0345	225	440.0345	665.0345	665.0345	0.237621619	9.464848
20	20.977	20.977	440.0345	400	440.0345	840.0345	840.0345	0.18811915	8.421456
25	20.977	20.977	440.0345	625	440.0345	1065.035	1065.035	0.148376956	7.479179
30	20.977	20.977	440.0345	900	440.0345	1340.035	1340.035	0.117927246	6.667726
35	20.977	20.977	440.0345	1225	440.0345	1665.035	1665.035	0.094908891	5.981693
40	20.977	20.977	440.0345	1600	440.0345	2040.035	2040.035	0.077462699	5.404021
45	20.977	20.977	440.0345	2025	440.0345	2465.035	2465.035	0.064107249	4.91614
50	20.977	20.977	440.0345	2500	440.0345	2940.035	2940.035	0.053749907	4.501524
55	20.977	20.977	440.0345	3025	440.0345	3465.035	3465.035	0.045606062	4.146503
60	20.977	20.977	440.0345	3600	440.0345	4040.035	4040.035	0.039115156	3.840106
65	20.977	20.977	440.0345	4225	440.0345	4665.035	4665.035	0.033874686	3.57362
70	20.977	20.977	440.0345	4900	440.0345	5340.035	5340.035	0.029592801	3.340133
75	20.977	20.977	440.0345	5625	440.0345	6065.035	6065.035	0.026055347	3.134145
80	20.977	20.977	440.0345	6400	440.0345	6840.035	6840.035	0.023103185	2.951254
85	20.977	20.977	440.0345	7225	440.0345	7665.035	7665.035	0.020616552	2.78791
90	20.977	20.977	440.0345	8100	440.0345	8540.035	8540.035	0.018504209	2.641228

95	20.977	20.977	440.0345	9025	440.0345	9465.035	9465.035	0.016695827	2.50885
100	20.977	20.977	440.0345	10000	440.0345	10440.03	10440.03	0.015136596	2.388827

Table 5.3 Power densities and electric fields obtained for 2100MHz

X (m)	**h (m)**	**$h-h_0$ (m)**	**h^2 (m^2)**	**X^2 (m^2)**	**$(h-h_0)^2$ (m^2)**	**R (m)**	**r (m)**	**P_d (W/m^2)**	**E(V/m)**
5	20.977	20.977	440.0345	25	440.0345	465.0345	465.0345	0.381280807	11.98928
10	20.977	20.977	440.0345	100	440.0345	540.0345	540.0345	0.328328525	11.12564
15	20.977	20.977	440.0345	225	440.0345	665.0345	665.0345	0.266615841	10.02568
20	20.977	20.977	440.0345	400	440.0345	840.0345	840.0345	0.211073157	8.920459
25	20.977	20.977	440.0345	625	440.0345	1065.035	1065.035	0.166481683	7.922348
30	20.977	20.977	440.0345	900	440.0345	1340.035	1340.035	0.132316546	7.062814
35	20.977	20.977	440.0345	1225	440.0345	1665.035	1665.035	0.106489528	6.336131
40	20.977	20.977	440.0345	1600	440.0345	2040.035	2040.035	0.086914578	5.724229
45	20.977	20.977	440.0345	2025	440.0345	2465.035	2465.035	0.071929516	5.20744
50	20.977	20.977	440.0345	2500	440.0345	2940.035	2940.035	0.060308387	4.768256
55	20.977	20.977	440.0345	3025	440.0345	3465.035	3465.035	0.051170844	4.392199
60	20.977	20.977	440.0345	3600	440.0345	4040.035	4040.035	0.043887927	4.067647
65	20.977	20.977	440.0345	4225	440.0345	4665.035	4665.035	0.038008023	3.78537
70	20.977	20.977	440.0345	4900	440.0345	5340.035	5340.035	0.033203669	3.538048
75	20.977	20.977	440.0345	5625	440.0345	6065.035	6065.035	0.029234581	3.319855
80	20.977	20.977	440.0345	6400	440.0345	6840.035	6840.035	0.0259222	3.126127
85	20.977	20.977	440.0345	7225	440.0345	7665.035	7665.035	0.023132152	2.953104
90	20.977	20.977	440.0345	8100	440.0345	8540.035	8540.035	0.020762064	2.797731
95	20.977	20.977	440.0345	9025	440.0345	9465.035	9465.035	0.018733026	2.657508
100	20.977	20.977	440.0345	10000	440.0345	10440.03	10440.03	0.01698354	2.530374

Consider h0=1.5m and other parameters kept constant, the results below were obtained.

Table 5.4 Power densities and electric fields obtained for 900MHz

X (m)	h (m)	$h-h_0$ (m)	h^2 (m2)	X^2 (m^2)	$(h-h_0)^2$ (m^2)	R (m)	r (m)	P_d (W/m^2)	E(V/m)
5	22.968	21.468	527.529	25	460.875	552.529	485.875	0.205213331	8.795762
10	22.968	21.468	527.529	100	460.875	627.529	560.875	0.17777228	8.186584
15	22.968	21.468	527.529	225	460.875	752.529	685.875	0.14537347	7.403094
20	22.968	21.468	527.529	400	460.875	927.529	860.875	0.115821727	6.607934
25	22.968	21.468	527.529	625	460.875	1152.529	1085.875	0.091822751	5.883636
30	22.968	21.468	527.529	900	460.875	1427.529	1360.875	0.073267589	5.255652
35	22.968	21.468	527.529	1225	460.875	1752.529	1685.875	0.059143193	4.721968
40	22.968	21.468	527.529	1600	460.875	2127.529	2060.875	0.048381406	4.270807
45	22.968	21.468	527.529	2025	460.875	2552.529	2485.875	0.040109833	3.888625
50	22.968	21.468	527.529	2500	460.875	3027.529	2960.875	0.033675191	3.563081
55	22.968	21.468	527.529	3025	460.875	3552.529	3485.875	0.028603444	3.283824
60	22.968	21.468	527.529	3600	460.875	4127.529	4060.875	0.024553337	3.042467
65	22.968	21.468	527.529	4225	460.875	4752.529	4685.875	0.021278423	2.832307
70	22.968	21.468	527.529	4900	460.875	5427.529	5360.875	0.018599208	2.648
75	22.968	21.468	527.529	5625	460.875	6152.529	6085.875	0.016383516	2.485274
80	22.968	21.468	527.529	6400	460.875	6927.529	6860.875	0.014532845	2.340701
85	22.968	21.468	527.529	7225	460.875	7752.529	7685.875	0.012972893	2.211511
90	22.968	21.468	527.529	8100	460.875	8627.529	8560.875	0.011646944	2.095447
95	22.968	21.468	527.529	9025	460.875	9552.529	9485.875	0.010511211	1.99066
100	22.968	21.468	527.529	10000	460.875	10527.53	10460.88	0.009531519	1.895622

Table 5.5 Power densities and electric fields obtained for 1800MHz.

X (m)	h (m)	$h-h_0$ (m)	h^2 (m2)	X^2 (m^2)	$(h-h_0)^2$ (m^2)	R (m)	r (m)	P_d (W/m^2)	E(V/m)
5	20.977	19.477	440.0345	25	379.3535	465.0345	404.3535	0.390812915	12.13822
10	20.977	19.477	440.0345	100	379.3535	540.0345	479.3535	0.329666043	11.14828
15	20.977	19.477	440.0345	225	379.3535	665.0345	604.3535	0.261480365	9.92865
20	20.977	19.477	440.0345	400	379.3535	840.0345	779.3535	0.202766236	8.743161
25	20.977	19.477	440.0345	625	379.3535	1065.035	1004.354	0.15734159	7.701804
30	20.977	19.477	440.0345	900	379.3535	1340.035	1279.354	0.123520651	6.824023
35	20.977	19.477	440.0345	1225	379.3535	1665.035	1604.354	0.098498603	6.093765
40	20.977	19.477	440.0345	1600	379.3535	2040.035	1979.354	0.079837472	5.486231
45	20.977	19.477	440.0345	2025	379.3535	2465.035	2404.354	0.065725185	4.97779
50	20.977	19.477	440.0345	2500	379.3535	2940.035	2879.354	0.05488266	4.54871
55	20.977	19.477	440.0345	3025	379.3535	3465.035	3404.354	0.046418969	4.183294
60	20.977	19.477	440.0345	3600	379.3535	4040.035	3979.354	0.039711622	3.869274
65	20.977	19.477	440.0345	4225	379.3535	4665.035	4604.354	0.034321122	3.597091
70	20.977	19.477	440.0345	4900	379.3535	5340.035	5279.354	0.029932942	3.359274
75	20.977	19.477	440.0345	5625	379.3535	6065.035	6004.354	0.026318667	3.149942
80	20.977	19.477	440.0345	6400	379.3535	6840.035	6779.354	0.023309978	2.964433
85	20.977	19.477	440.0345	7225	379.3535	7665.035	7604.354	0.020781067	2.799011
90	20.977	19.477	440.0345	8100	379.3535	8540.035	8479.354	0.018636631	2.650662
95	20.977	19.477	440.0345	9025	379.3535	9465.035	9404.354	0.016803556	2.516931
100	20.977	19.477	440.0345	10000	379.3535	10440.03	10379.35	0.015225089	2.3958

Table 5.6 Power densities and electric fields obtained for 2100 MHz

X (m)	h (m)	$h-h_0$ (m)	h^2 (m2)	X^2 (m^2)	$(h-h_0)^2$	R (m)	r (m)	P_d (W/m^2)	E(V/m)
5	20.977	19.477	440.0345	25	379.3535	465.0345	404.3535	0.438499302	12.85746
10	20.977	19.477	440.0345	100	379.3535	540.0345	479.3535	0.369891384	11.80885

15	20.977	19.477	440.0345	225	379.3535	665.0345	604.3535	0.293385795	10.51696
20	20.977	19.477	440.0345	400	379.3535	840.0345	779.3535	0.227507458	9.261226
25	20.977	19.477	440.0345	625	379.3535	1065.035	1004.354	0.176540168	8.158164
30	20.977	19.477	440.0345	900	379.3535	1340.035	1279.354	0.13859245	7.228371
35	20.977	19.477	440.0345	1225	379.3535	1665.035	1604.354	0.11051725	6.454843
40	20.977	19.477	440.0345	1600	379.3535	2040.035	1979.354	0.089579117	5.81131
45	20.977	19.477	440.0345	2025	379.3535	2465.035	2404.354	0.073744871	5.272743
50	20.977	19.477	440.0345	2500	379.3535	2940.035	2879.354	0.061579358	4.818238
55	20.977	19.477	440.0345	3025	379.3535	3465.035	3404.354	0.05208294	4.43117
60	20.977	19.477	440.0345	3600	379.3535	4040.035	3979.354	0.044557172	4.098543
65	20.977	19.477	440.0345	4225	379.3535	4665.035	4604.354	0.038508933	3.810232
70	20.977	19.477	440.0345	4900	379.3535	5340.035	5279.354	0.033585313	3.558323
75	20.977	19.477	440.0345	5625	379.3535	6065.035	6004.354	0.02953003	3.336588
80	20.977	19.477	440.0345	6400	379.3535	6840.035	6779.354	0.026154225	3.140086
85	20.977	19.477	440.0345	7225	379.3535	7665.035	7604.354	0.023316741	2.964863
90	20.977	19.477	440.0345	8100	379.3535	8540.035	8479.354	0.020910644	2.807724
95	20.977	19.477	440.0345	9025	379.3535	9465.035	9404.354	0.0188539	2.666068
100	20.977	19.477	440.0345	10000	379.3535	10440.03	10379.35	0.017082831	2.53776

Now consider h0=2m (Assuming 2m the maximum height for men), the following results were obtained.

Table 5.7 Power densities and electric fields obtained for 900MHz

X (m)	**h (m)**	**$h-h_0$ (m)**	**h^2 (m2)**	**X^2 (m^2)**	**$(h-h_0)^2$ (m^2)**	**R (m)**	**r (m)**	**P_d (W/m^2)**	**E(V/m)**
5	22.968	20.968	527.529	25	439.657	552.529	464.657	0.214584149	8.994344
10	22.968	20.968	527.529	100	439.657	627.529	539.657	0.184761854	8.34597
15	22.968	20.968	527.529	225	439.657	752.529	664.657	0.150014261	7.520331

20	22.968	20.968	527.529	400	439.657	927.529	839.657	0.118748524	6.690904
25	22.968	20.968	527.529	625	439.657	1152.529	1064.657	0.093652726	5.941976
30	22.968	20.968	527.529	900	439.657	1427.529	1339.657	0.074428029	5.297109
35	22.968	20.968	527.529	1225	439.657	1752.529	1664.657	0.059897042	4.751966
40	22.968	20.968	527.529	1600	439.657	2127.529	2039.657	0.048884705	4.292963
45	22.968	20.968	527.529	2025	439.657	2552.529	2464.657	0.040455135	3.905328
50	22.968	20.968	527.529	2500	439.657	3027.529	2939.657	0.033918253	3.575917
55	22.968	20.968	527.529	3025	439.657	3552.529	3464.657	0.028778615	3.293864
60	22.968	20.968	527.529	3600	439.657	4127.529	4039.657	0.024682301	3.050447
65	22.968	20.968	527.529	4225	439.657	4752.529	4664.657	0.021375212	2.838742
70	22.968	20.968	527.529	4900	439.657	5427.529	5339.657	0.018673115	2.653255
75	22.968	20.968	527.529	5625	439.657	6152.529	6064.657	0.016440836	2.489617
80	22.968	20.968	527.529	6400	439.657	6927.529	6839.657	0.014577929	2.344329
85	22.968	20.968	527.529	7225	439.657	7752.529	7664.657	0.013008805	2.21457
90	22.968	20.968	527.529	8100	439.657	8627.529	8539.657	0.011675883	2.098049
95	22.968	20.968	527.529	9025	439.657	9552.529	9464.657	0.010534775	1.99289
100	22.968	20.968	527.529	10000	439.657	10527.53	10439.66	0.009550892	1.897547

Table 5.8 Power densities and electric fields obtained for 1800MHz

X (m)	**h (m)**	**$h-h_0$ (m)**	**h^2 (m2)**	**X^2 (m^2)**	**$(h-h_0)^2$**	**R (m)**	**r (m)**	**P_d (W/m^2)**	**E(V/m)**
5	20.977	18.977	440.0345	25	360.1265	465.0345	385.1265	0.410323801	12.43753
10	20.977	18.977	440.0345	100	360.1265	540.0345	460.1265	0.343441578	11.37882
15	20.977	18.977	440.0345	225	360.1265	665.0345	585.1265	0.270072494	10.09046
20	20.977	18.977	440.0345	400	360.1265	840.0345	760.1265	0.207895101	8.853048
25	20.977	18.977	440.0345	625	360.1265	1065.035	985.1265	0.160412471	7.7766
30	20.977	18.977	440.0345	900	360.1265	1340.035	1260.127	0.125405328	6.875886
35	20.977	18.977	440.0345	1225	360.1265	1665.035	1585.127	0.099693355	6.130611
40	20.977	18.977	440.0345	1600	360.1265	2040.035	1960.127	0.080620602	5.513072

45	20.977	18.977	440.0345	2025	360.1265	2465.035	2385.127	0.06625501	4.997813
50	20.977	18.977	440.0345	2500	360.1265	2940.035	2860.127	0.055251605	4.563974
55	20.977	18.977	440.0345	3025	360.1265	3465.035	3385.127	0.046682622	4.195158
60	20.977	18.977	440.0345	3600	360.1265	4040.035	3960.127	0.039904427	3.878656
65	20.977	18.977	440.0345	4225	360.1265	4665.035	4585.127	0.034465043	3.604625
70	20.977	18.977	440.0345	4900	360.1265	5340.035	5260.127	0.030042354	3.365407
75	20.977	18.977	440.0345	5625	360.1265	6065.035	5985.127	0.026403215	3.154998
80	20.977	18.977	440.0345	6400	360.1265	6840.035	6760.127	0.023376276	2.968645
85	20.977	18.977	440.0345	7225	360.1265	7665.035	7585.127	0.020833744	2.802556
90	20.977	18.977	440.0345	8100	360.1265	8540.035	8460.127	0.018678986	2.653672
95	20.977	18.977	440.0345	9025	360.1265	9465.035	9385.127	0.016837981	2.519508
100	20.977	18.977	440.0345	10000	360.1265	10440.03	10360.13	0.015253345	2.398022

Table 5.9 Power densities and electric fields obtained for 2100MHz

X (m)	**h (m)**	**h-h_0 (m)**	**h^2 (m2)**	**X^2 (m^2)**	**$(h-h_0)^2$**	**R (m)**	**r (m)**	**P_d (W/m^2)**	**E(V/m)**
5	20.977	18.977	440.0345	25	360.1265	465.0345	385.1265	0.460390877	13.1745
10	20.977	18.977	440.0345	100	360.1265	540.0345	460.1265	0.385347789	12.05305
15	20.977	18.977	440.0345	225	360.1265	665.0345	585.1265	0.303026323	10.68835
20	20.977	18.977	440.0345	400	360.1265	840.0345	760.1265	0.233262139	9.377624
25	20.977	18.977	440.0345	625	360.1265	1065.035	985.1265	0.179985753	8.237392
30	20.977	18.977	440.0345	900	360.1265	1340.035	1260.127	0.140707093	7.283308
35	20.977	18.977	440.0345	1225	360.1265	1665.035	1585.127	0.111857784	6.493873
40	20.977	18.977	440.0345	1600	360.1265	2040.035	1960.127	0.090457804	5.839742
45	20.977	18.977	440.0345	2025	360.1265	2465.035	2385.127	0.074339344	5.293952
50	20.977	18.977	440.0345	2500	360.1265	2940.035	2860.127	0.06199332	4.834406
55	20.977	18.977	440.0345	3025	360.1265	3465.035	3385.127	0.052378763	4.443736
60	20.977	18.977	440.0345	3600	360.1265	4040.035	3960.127	0.044773504	4.10848
65	20.977	18.977	440.0345	4225	360.1265	4665.035	4585.127	0.038670414	3.818212

70	20.977	18.977	440.0345	4900	360.1265	5340.035	5260.127	0.033708075	3.56482
75	20.977	18.977	440.0345	5625	360.1265	6065.035	5985.127	0.029624894	3.341943
80	20.977	18.977	440.0345	6400	360.1265	6840.035	6760.127	0.026228613	3.144549
85	20.977	18.977	440.0345	7225	360.1265	7665.035	7585.127	0.023375845	2.968618
90	20.977	18.977	440.0345	8100	360.1265	8540.035	8460.127	0.020958167	2.810912
95	20.977	18.977	440.0345	9025	360.1265	9465.035	9385.127	0.018892525	2.668798
100	20.977	18.977	440.0345	10000	360.1265	10440.03	10360.13	0.017114534	2.540114

With other parameters constant, now consider typical h0 =4.0m for a typical height of a normal house rooftop

Table 5.10 Power densities and electric fields obtained for 900MHz

X (m)	h (m)	$h-h_0$ (m)	h^2 (m2)	X^2 (m^2)	$(h-h_0)^2$ (m^2)	R (m)	r (m)	P_d (W/m^2)	E(V/m)
5	22.968	18.968	527.529	25	359.785	552.529	384.785	0.259126592	9.883862
10	22.968	18.968	527.529	100	359.785	627.529	459.785	0.216857938	9.041872
15	22.968	18.968	527.529	225	359.785	752.529	584.785	0.170503737	8.017475
20	22.968	18.968	527.529	400	359.785	927.529	759.785	0.1312319	7.033806
25	22.968	18.968	527.529	625	359.785	1152.529	984.785	0.101248526	6.178244
30	22.968	18.968	527.529	900	359.785	1427.529	1259.785	0.079146862	5.462451
35	22.968	18.968	527.529	1225	359.785	1752.529	1584.785	0.062915809	4.870242
40	22.968	18.968	527.529	1600	359.785	2127.529	1959.785	0.050877025	4.379571
45	22.968	18.968	527.529	2025	359.785	2552.529	2384.785	0.041810071	3.970189
50	22.968	18.968	527.529	2500	359.785	3027.529	2859.785	0.034865569	3.62551
55	22.968	18.968	527.529	3025	359.785	3552.529	3384.785	0.029457715	3.3325
60	22.968	18.968	527.529	3600	359.785	4127.529	3959.785	0.025180163	3.081058
65	22.968	18.968	527.529	4225	359.785	4752.529	4584.785	0.021747592	2.863362
70	22.968	18.968	527.529	4900	359.785	5427.529	5259.785	0.018956674	2.673325

75	22.968	18.968	527.529	5625	359.785	6152.529	5984.785	0.016660253	2.506175
80	22.968	18.968	527.529	6400	359.785	6927.529	6759.785	0.014750178	2.358138
85	22.968	18.968	527.529	7225	359.785	7752.529	7584.785	0.013145795	2.2262
90	22.968	18.968	527.529	8100	359.785	8627.529	8459.785	0.011786119	2.10793
95	22.968	18.968	527.529	9025	359.785	9552.529	9384.785	0.010624434	2.001352
100	22.968	18.968	527.529	10000	359.785	10527.53	10359.79	0.009624527	1.904848

Table 5.11 Power densities and electric fields obtained for 1800MHz

X (m)	h (m)	$h-h_0$ (m)	h^2 (m2)	X^2 (m^2)	$(h-h_0)^2$	R (m)	r (m)	P_d (W/m^2)	E(V/m)
5	20.977	16.977	440.0345	25	288.2185	465.0345	313.2185	0.504525009	13.79152
10	20.977	16.977	440.0345	100	288.2185	540.0345	388.2185	0.407055742	12.3879
15	20.977	16.977	440.0345	225	288.2185	665.0345	513.2185	0.307912853	10.77419
20	20.977	16.977	440.0345	400	288.2185	840.0345	688.2185	0.229616865	9.304061
25	20.977	16.977	440.0345	625	288.2185	1065.035	913.2185	0.173043556	8.076969
30	20.977	16.977	440.0345	900	288.2185	1340.035	1188.219	0.132994544	7.080886
35	20.977	16.977	440.0345	1225	288.2185	1665.035	1513.219	0.104430773	6.274584
40	20.977	16.977	440.0345	1600	288.2185	2040.035	1888.219	0.083690833	5.617067
45	20.977	16.977	440.0345	2025	288.2185	2465.035	2313.219	0.068314593	5.074899
50	20.977	16.977	440.0345	2500	288.2185	2940.035	2788.219	0.056676541	4.622451
55	20.977	16.977	440.0345	3025	288.2185	3465.035	3313.219	0.047695792	4.240438
60	20.977	16.977	440.0345	3600	288.2185	4040.035	3888.219	0.040642412	3.914357
65	20.977	16.977	440.0345	4225	288.2185	4665.035	4513.219	0.035014166	3.633227
70	20.977	16.977	440.0345	4900	288.2185	5340.035	5188.219	0.030458737	3.388649
75	20.977	16.977	440.0345	5625	288.2185	6065.035	5913.219	0.026724292	3.174123
80	20.977	16.977	440.0345	6400	288.2185	6840.035	6688.219	0.023627604	2.984561
85	20.977	16.977	440.0345	7225	288.2185	7665.035	7513.219	0.021033141	2.815936
90	20.977	16.977	440.0345	8100	288.2185	8540.035	8388.219	0.018839111	2.665022
95	20.977	16.977	440.0345	9025	288.2185	9465.035	9313.219	0.016967988	2.529216

100	20.977	16.977	440.0345	10000	288.2185	10440.03	10288.22	0.015359956	2.406388

Table 5.12 Power densities and electric fields obtained for 2100 MHz

X (m)	h (m)	$h-h_0$ (m)	h^2 (m2)	X^2 (m^2)	$(h-h_0)^2$	R (m)	r (m)	P_d (W/m^2)	E(V/m)
5	20.977	16.977	440.0345	25	288.2185	465.0345	313.2185	0.566086371	14.60872
10	20.977	16.977	440.0345	100	288.2185	540.0345	388.2185	0.456724054	13.12193
15	20.977	16.977	440.0345	225	288.2185	665.0345	513.2185	0.345483903	11.4126
20	20.977	16.977	440.0345	400	288.2185	840.0345	688.2185	0.25763436	9.855362
25	20.977	16.977	440.0345	625	288.2185	1065.035	913.2185	0.194158063	8.555559
30	20.977	16.977	440.0345	900	288.2185	1340.035	1188.219	0.149222333	7.500455
35	20.977	16.977	440.0345	1225	288.2185	1665.035	1513.219	0.117173255	6.646376
40	20.977	16.977	440.0345	1600	288.2185	2040.035	1888.219	0.093902659	5.949899
45	20.977	16.977	440.0345	2025	288.2185	2465.035	2313.219	0.076650234	5.375606
50	20.977	16.977	440.0345	2500	288.2185	2940.035	2788.219	0.063592125	4.896349
55	20.977	16.977	440.0345	3025	288.2185	3465.035	3313.219	0.053515559	4.4917
60	20.977	16.977	440.0345	3600	288.2185	4040.035	3888.219	0.045601537	4.146297
65	20.977	16.977	440.0345	4225	288.2185	4665.035	4513.219	0.03928654	3.84851
70	20.977	16.977	440.0345	4900	288.2185	5340.035	5188.219	0.034175264	3.589439
75	20.977	16.977	440.0345	5625	288.2185	6065.035	5913.219	0.029985149	3.362202
80	20.977	16.977	440.0345	6400	288.2185	6840.035	6688.219	0.026510608	3.161408
85	20.977	16.977	440.0345	7225	288.2185	7665.035	7513.219	0.023599572	2.98279
90	20.977	16.977	440.0345	8100	288.2185	8540.035	8388.219	0.02113783	2.822935
95	20.977	16.977	440.0345	9025	288.2185	9465.035	9313.219	0.019038396	2.679081
100	20.977	16.977	440.0345	10000	288.2185	10440.03	10288.22	0.017234154	2.548975

4.3 Two source modelling

Case2: Exposure to 2 sources.

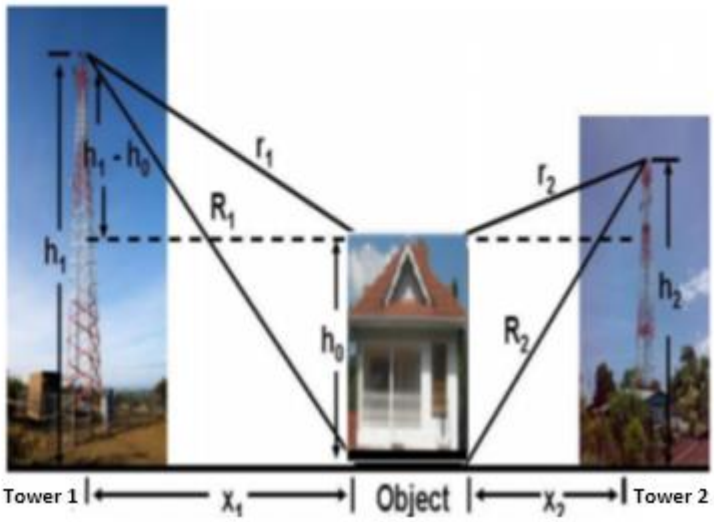

Figure 5.2 Model to simulate two sources scenario.

The two source scenario has been simulated using below equation:

$$P_{\mathrm{d}} = P_{\mathrm{d},1} + P_{\mathrm{d},2} = \frac{1}{4\pi}\left[\left(\frac{P_1 G_1}{(h_1 - h_0)^2 + {x_1}^2}\right) + \left(\frac{P_2 G_2}{(h_2 - h_0)^2 + {x_2}^2}\right)\right] \text{.........(from 2.30)}$$

Figure 5.3 Two base stations in proximity at Greencroft shops in Harare, Zimbabwe

Assumptions: Assume 50m separation distance of 50m, same antenna height of 20.977m, A house of average height 4m in between the two sources and assume exposure to two 2100MHz bands (Since 2100MHz antennas being used have higher gain compared to 1800 and 900, this would provide a better worst case scenario).

Table 5.13 Power densities and electric fields obtained for two sources exposure to 2100MHz

X_1 (m)	X_2 (m)	h_1 (m)	h_2(m)	P_{d1} (W/m^2)	P_{d2} (W/m^2)	P_d (W/m^2)	E_T(V/m)
5	95	20.977	20.977	0.566086	0.019038	0.585125	14.85234
10	90	20.977	20.977	0.456724	0.021138	0.477862	13.42214
15	85	20.977	20.977	0.345484	0.0236	0.369083	11.79595
20	80	20.977	20.977	0.257634	0.026511	0.284145	10.35001
25	75	20.977	20.977	0.194158	0.029985	0.224143	9.192496
30	70	20.977	20.977	0.149222	0.034175	0.183398	8.3151
35	65	20.977	20.977	0.117173	0.039287	0.15646	7.680192
40	60	20.977	20.977	0.093903	0.045602	0.139504	7.252109
45	55	20.977	20.977	0.07665	0.053516	0.130166	7.005177
50	50	20.977	20.977	0.063592	0.063592	0.127184	6.924483
55	45	20.977	20.977	0.053516	0.07665	0.130166	7.005177
60	40	20.977	20.977	0.045602	0.093903	0.139504	7.252109
65	35	20.977	20.977	0.039287	0.117173	0.15646	7.680192
70	30	20.977	20.977	0.034175	0.149222	0.183398	8.3151
75	25	20.977	20.977	0.029985	0.194158	0.224143	9.192496
80	20	20.977	20.977	0.026511	0.257634	0.284145	10.35001
85	15	20.977	20.977	0.0236	0.345484	0.369083	11.79595
90	10	20.977	20.977	0.021138	0.456724	0.477862	13.42214
95	5	20.977	20.977	0.019038	0.566086	0.585125	14.85234
100	0	20.977	20.977	0.017234	0.615189	0.632423	15.44096

Table 5.14 Power densities and electric fields obtained for two source exposure to 2100MHz for object an object of height h0=2m

X_1 (m)	X_2 (m)	h_1 (m)	h_2(m)	P_{d1} (W/m^2)	P_{d2} (W/m^2)	P_d (W/m^2)	E_T(V/m)
5	95	20.977	20.977	0.460391	0.018893	0.479283	13.44209
10	90	20.977	20.977	0.385348	0.020958	0.406306	12.37648
15	85	20.977	20.977	0.303026	0.023376	0.326402	11.09295
20	80	20.977	20.977	0.233262	0.026229	0.259491	9.890804
25	75	20.977	20.977	0.179986	0.029625	0.209611	8.8895
30	70	20.977	20.977	0.140707	0.033708	0.174415	8.108916
35	65	20.977	20.977	0.111858	0.03867	0.150528	7.533202
40	60	20.977	20.977	0.090458	0.044774	0.135231	7.140182
45	55	20.977	20.977	0.074339	0.052379	0.126718	6.911782
50	50	20.977	20.977	0.061993	0.061993	0.123987	6.836883
55	45	20.977	20.977	0.052379	0.074339	0.126718	6.911782
60	40	20.977	20.977	0.044774	0.090458	0.135231	7.140182
65	35	20.977	20.977	0.03867	0.111858	0.150528	7.533202
70	30	20.977	20.977	0.033708	0.140707	0.174415	8.108916
75	25	20.977	20.977	0.029625	0.179986	0.209611	8.8895
80	20	20.977	20.977	0.026229	0.233262	0.259491	9.890804
85	15	20.977	20.977	0.023376	0.303026	0.326402	11.09295
90	10	20.977	20.977	0.020958	0.385348	0.406306	12.37648
95	5	20.977	20.977	0.018893	0.460391	0.479283	13.44209
100	0	20.977	20.977	0.017115	0.492351	0.509466	13.85888

Table 5.15 Power densities and Electric fields obtained for exposure to two sources at 2100MHz for an object of height object h0= 1.5 m

X_1 (m)	X_2 (m)	h_1 (m)	h_2(m)	P_{d1} (W/m^2)	P_{d2} (W/m^2)	P_d (W/m^2)	E_T(V/m)
5	95	20.977	20.977	0.438499	0.018854	0.457353	13.13096
10	90	20.977	20.977	0.369891	0.020911	0.390802	12.13805
15	85	20.977	20.977	0.293386	0.023317	0.316703	10.92689
20	80	20.977	20.977	0.227507	0.026154	0.253662	9.779083
25	75	20.977	20.977	0.17654	0.02953	0.20607	8.814106
30	70	20.977	20.977	0.138592	0.033585	0.172178	8.056737
35	65	20.977	20.977	0.110517	0.038509	0.149026	7.495523
40	60	20.977	20.977	0.089579	0.044557	0.134136	7.111215
45	55	20.977	20.977	0.073745	0.052083	0.125828	6.887459
50	50	20.977	20.977	0.061579	0.061579	0.123159	6.814018
55	45	20.977	20.977	0.052083	0.073745	0.125828	6.887459
60	40	20.977	20.977	0.044557	0.089579	0.134136	7.111215
65	35	20.977	20.977	0.038509	0.110517	0.149026	7.495523
70	30	20.977	20.977	0.033585	0.138592	0.172178	8.056737
75	25	20.977	20.977	0.02953	0.17654	0.20607	8.814106
80	20	20.977	20.977	0.026154	0.227507	0.253662	9.779083
85	15	20.977	20.977	0.023317	0.293386	0.316703	10.92689
90	10	20.977	20.977	0.020911	0.369891	0.390802	12.13805
95	5	20.977	20.977	0.018854	0.438499	0.457353	13.13096
100	0	20.977	20.977	0.017083	0.467397	0.48448	13.51477

Table 5.16 Power densities and Electric fields obtained for exposure to two sources at 2100MHz for an object of height object h0 = 0m

X_1 (m)	X_2 (m)	P_{d1} (W/m^2)	P_{d2} (W/m^2)	P_d (W/m^2)	E_1(V/m)	E_2(V/m)	E_T(V/m)

5	95	0.320664	0.018561	0.339225	10.99501	2.645253	11.30874
10	90	0.282365	0.020551	0.302915	10.31753	2.783442	10.68639
15	85	0.235488	0.02287	0.258358	9.422255	2.936314	9.869185
20	80	0.191077	0.025593	0.216671	8.48741	3.10623	9.037964
25	75	0.153788	0.028817	0.182605	7.614334	3.296054	8.297111
30	70	0.124171	0.032666	0.156837	6.841958	3.509281	7.689437
35	65	0.101149	0.037305	0.138454	6.175213	3.7502	7.224767
40	60	0.083324	0.042953	0.126277	5.604744	4.024101	6.89975
45	55	0.069453	0.049905	0.119357	5.116998	4.337522	6.708037
50	50	0.058557	0.058557	0.117115	4.698529	4.698529	6.644724
55	45	0.049905	0.069453	0.119357	4.337522	5.116998	6.708037
60	40	0.042953	0.083324	0.126277	4.024101	5.604744	6.89975
65	35	0.037305	0.101149	0.138454	3.7502	6.175213	7.224767
70	30	0.032666	0.124171	0.156837	3.509281	6.841958	7.689437
75	25	0.028817	0.153788	0.182605	3.296054	7.614334	8.297111
80	20	0.025593	0.191077	0.216671	3.10623	8.48741	9.037964
85	15	0.02287	0.235488	0.258358	2.936314	9.422255	9.869185
90	10	0.020551	0.282365	0.302915	2.783442	10.31753	10.68639
95	5	0.018561	0.320664	0.339225	2.645253	10.99501	11.30874
100	0	0.016842	0.335849	0.35269	2.519788	11.25233	11.53101

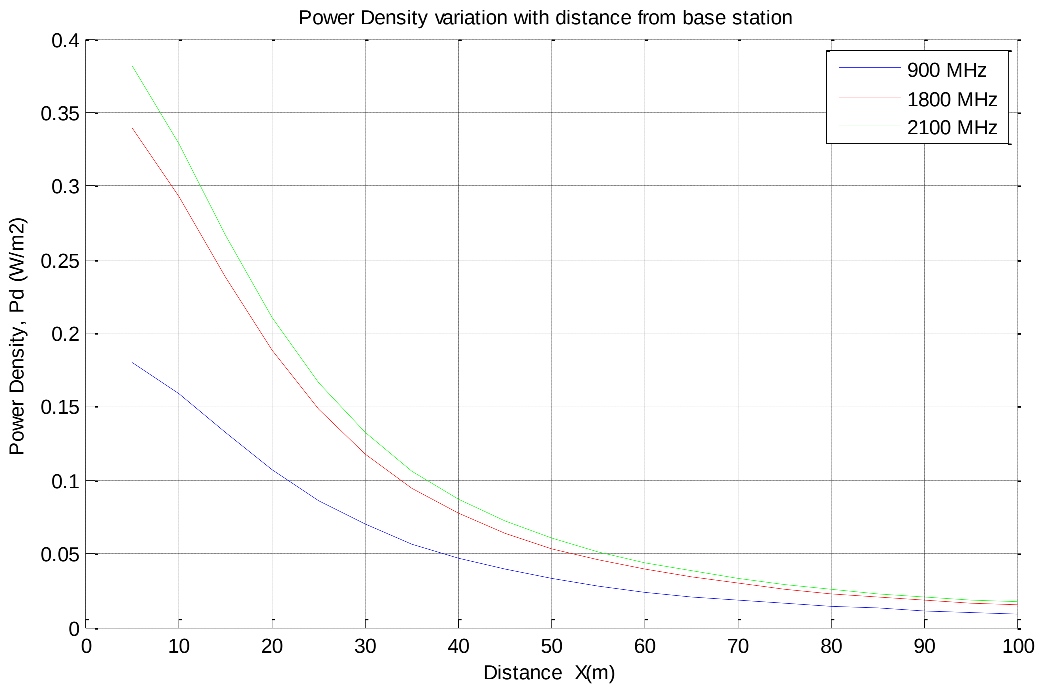

Figure 5.4 Variation of Power Density with distance from the base station carrying 900MHz, 1800MHz and 2100MHz bands.

From figure above, it can be noted that power radiated by the mobile base station antenna decrease with increase in distance from the base station site. The power levels at 5m away from the base station decreases dramatically at a rate of $1/R^2$ (where R is distance from antenna) from just above $0.375W/m^2$ to near zero power level several metres away. It can also be noted that the graph for 900MHz, which is the lowest transmit frequency, is radiating the least power. 1800MHz is the intermediate with the 2100MHz being the highest producer of RF radiation. This is mainly because of the higher gain levels of the antenna for 3G (19.5dBi) compared to 1800MHz (19dBi) and 900MHz (17dBi).

Since higher frequency suffers more attenuation than lower frequency, this implies that 2100MHz suffers more attenuation than 1800 and 900MHz and thus, more power is needed to drive RF signals for 3G compared to 2G (1800 and 900MHz) assuming same receive levels are desired at a certain distance of reference.

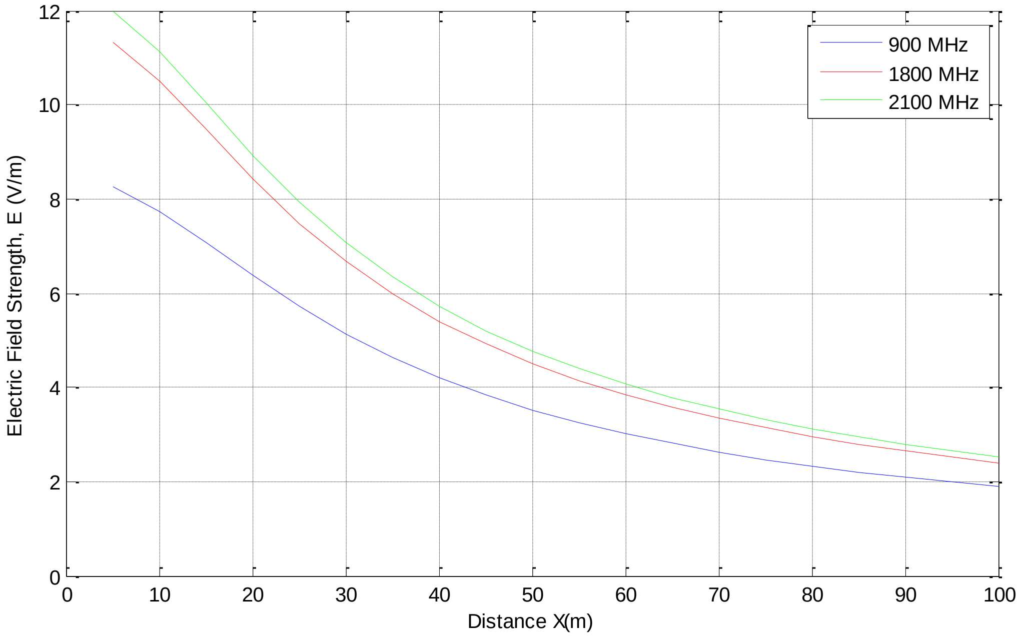

Figure 5.5 Variation of Electric Field strength with distance from the base station carrying 900MHz, 1800MHz and 2100MHz bands.

From the figure above, it can be noted that electric field strength decreases with increase in distance from the mobile base station. The electric field strength profile for 2100MHz is the highest followed by 1800MHz and 900MHz respectively, in order of decreasing frequencies. The electric field strength profiles for all the three bands do not equate to zero as distance increases. Since these are electromagnetic waves in space, once they leave the near field region, the electric and magnetic field components are fully formed and they efficiently propagate in space independent of the transmitting antenna and thus, measurement from a distance continues to give voltages of the now off-the air signal though this will be very small.

The pattern of the profiles above are mainly due to the differences in the antenna gains of the three bands and the higher the gain, the higher the electric field strength profile. At 5m away, for 2100MHz is nearly 12V/m and significantly drops to just below 3V some 100m away. The 1800MHz profile is just above 11.2 V/m at 5m away and drops to about 2V/m a hundred meters away. The 900MHz profile starts at about 8.2V/m at 5m away and drops to below 2V/m at 100m distance away. The frequency attenuation relationship still holds.

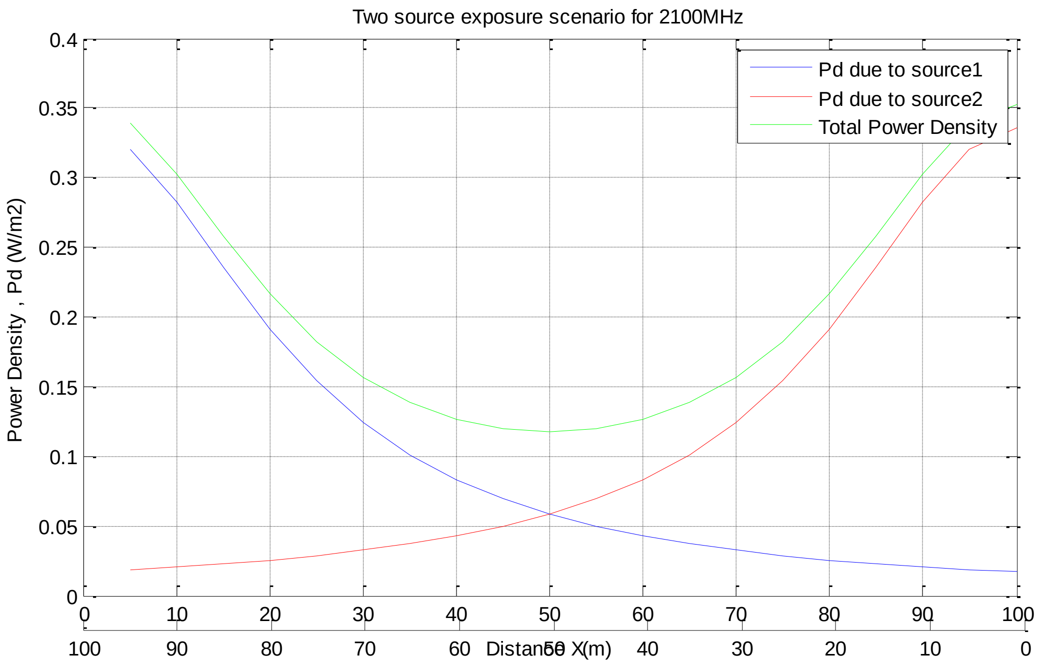

Figure 5.6 Variation of power densities with distance between two sources in proximity.

Figure above shows that the individual profiles from the two sources are identical. This is because the same gain of 19.5dBi has been applied to both the antennas on both side and this is the case for the 2100MHz antenna which has the highest gain compared to the other two bands. Using the highest gain for two antennas also give a better worst case scenario compared to the rest scenarios possible in this context. For both sources, which are 100m away from each, show a regular decrease in power density as one moves away from either source. Now taking into account the additive nature of the radiated power levels for multi sources radiation (due to superposition of EM waves), at the midway between the sources, an object which had to experience just above $0.05w/m^2$ will now be exposed to about $0.13W/m^2$

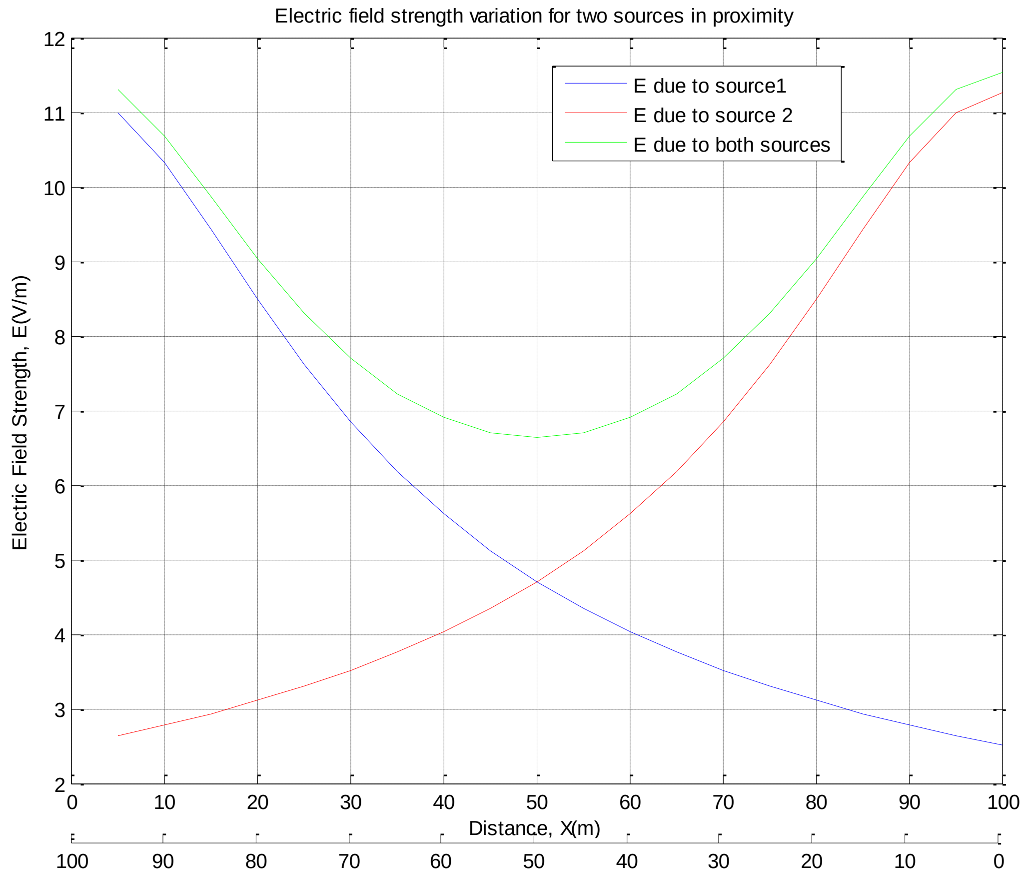

Figure 5.7 Variation of electric field strengths with distance between two sources in proximity.

Above electric field profiles for the two sources are identical due to same reasons as above mentioned in power density profiling. At 50m away, that is, in the midway between the two sources, the field strength is expected to be very low if sources were to be considered individually. Rather, a significant increase in the electric field strength levels is witnessed as these fields are additive. The field strength significantly rise from about 4.75V/m to just below 6.75 V/m

Considering the above simulated scenarios, the more worrying scenario comes when many sources are very close in distance. Two more sources with conditions as above would give the same contribution and thus, the field strength and power density levels would be expected to double the current levels produced by the existing two sources.

With the high levels of attenuation in the atmosphere, power density levels are expected to be far much lower than obtained.

CHAPTER 5

CONCLUSION

5.1 Introduction

This chapter stands to sum up what transpired in the whole research. The researcher goes on to give recommendations to relevant stakeholders concerning the findings of the research. A final conclusion is also included in a nutshell to give the importance of the research and the way forward.

5.2 Key findings

High power density levels and electric field strengths were identified in the 10m radius from the base station and these levels fall drastically as distance increases. The highest power density values obtained for 900MHz is 0.18W/m^2, 1800MHz=0.34W/m^2, 2100MHz is 0.38W/m^2 and the Electric field strengths as 8.25V/m, 11.32V/m and 11.99V/m, with all these witnessed within 10m radius.

The levels obtained are well below ICNIRP guidelines given in chapter 2, the reference levels which are set to ensure basic restrictions are not exceeded. For general public, Electric field strength for 400-2000MHz is set at $1.375f^{1/2}$ and 61V for frequencies 2-300GHz.

Corresponding power density levels are at f/200 for frequencies 400-2000MHz, and 10W/m^2 for frequencies 2-300GHz.

5.2.1 Safe distance deduction

With the high levels of attenuation in the atmosphere, power density levels are expected to be far much lower than obtained. Considering the 25m height towers, which in this area of study was the minimum tower height and antenna height at 20m, this would mean that the near field on the bottom of the antenna would almost be at its end (23.7m for 900MHZ, 46.9m for 1800MHz, 54.5m for 2100MHz) for 900MHz, and almost halved for the other bands. Also this near field at the bottom of the antenna would come as a minor lobe which would be not as effective as the main lobe. Also, the main lobe at such a height does not instantly hit the ground which means that it can go to tens of meters before being incident on the ground and even hundreds of metres away, where by then the power density would be extremely lower than expected. However, this depends on tilting present on the antenna which may be ectrical or mechanical. This therefore means that an object at a distance of 20m near the base station may have a chance to be at a ‘blind spot’ and safer than an object 300m away engulfed by the main beam.

The metallic tower itself and the fencing also amplify the signal. With at least 20m antenna height and no significant down tilting of the antenna, exposure levels are very weak near the base station since this would not be having the main lobe, which would be incident at the ground when its power levels have significantly dropped. Basing on the results of this research, at least 10m radius from the base station fencing is needed to be out of the near field and the effect of amplification by the fencing and tower which could modify the signal significantly. A 10m radius from the fence would mean the signal would be extremely weak and the effect of the fencing would be almost not existant if at all.

5.3 Challenges faced

The major blow in the research was the malfunctioning of the SMP tool which was the main apparatus to perform the measurements with. Near field conditions simulation problems since this region is complicated even to measure using an instrument.

5.4 Recommendations

The initial step in countering EMF issues is first accepting that there is need. With the emitted levels well below guidelines, the main issue is on the time span that humans are exposed to. Above all, all stakeholders should promote research in the issue and reduce uncertainties.

5.5 Recommendations to Mobile operators

The researcher recommends that the mobile operator should regularly educate the public in as far as EMF issues are concerned. The operators are also encouraged to have their own measuring tools and provide information regularly to the public so that they continue gaining confidence of the public. The operators should interact with the public through their websites or via USSD services.

5.6 Recommendations to the general Public

The general public should not panic but rather seek relevant information concerning EMF issues. The public should also take the opportunity of the internet to seek more information.

5.7 Recommendations to the Government

The government should protract clear roles and responsibilities regarding EMF issues [1]. It should have its own tailored frameworks to deal with EMF issues rather than merely adopting international standards which though universal, may not necessarily fit the varying conditions in each and every country. International standards should be considered as a stepping stone to derive measures that suits best for all stakeholders in the country. The government must maintain a relevant point of contact to the international health organisations dealing with EMF issues [2].

5.8 Conclusion

The research has revealed that mobile base station antennas produce EMF radiation that the environment is exposed to. Radiation levels for each band has been determined and also the effect of multi sources in proximity to an object, with the most worrying being human beings. It has been revealed by the research that the level of exposure depends on the number of sources, the gain of the transmitting antenna, the power level transmitted per carrier and also the height of the antenna among other factors. The safe region has been concluded to be outside the near field which is difficult to model at high precision and accuracy. For the area of study scenario, at least 10m distance from the base station site fencing is recommended.

5.9 Future Work

With 2014-2017 been declared a new EMF exposure research period by WHO, this research has served as an eye opener of what needs to be done in the country in as far as EMF issues are concerned. The research also can be done on a larger scale since exposure scenarios are always different depending on the subscriber density, services accessed among other factors. Tools of high credibility are required and these have to be frequency selective for valid measurements. Researchers need to further look into the impact of minute electric currents and magnetic fields induced into objects by EMF fields. Research is also needed on the EMF levels emanating from mobile phones themselves as these can be more dangerous than the mobile base stations since these are too close to humans and have higher power levels that they push compared to the receive levels they get from the mobile base stations.

References

[1] E, Van, Deventer : World Health Organisation, "The International EMF project," in *Switzerland*, Geneva, April 2015.

[2] T. I. E. project, "The International EMF project: Progress Report," June 2013-2014.

APPENDIX A

Software algorithm

```
  clear all
X = [
    %%
    %
    % <<FILENAME.PNG>>
    %
0.120617
0.121473
0.122321
0.123159
0.123987
0.124804
0.12561
0.126403
0.127184
0.127952
0.128705
0.129444
0.130168
0.130875
0.131566
0.13224
0.132895
0.133532
0.13415
0.134747

]; % dependent vectors of interest
Y = [0.457353
0.390802
0.316703
0.253662
0.20607
0.172178
0.149026
0.134136
0.125828
0.123159
0.125828
0.134136
0.149026
0.172178
0.20607
0.253662
0.316703
0.390802
0.457353
0.48448

];
Z = [0.479283
0.406306
0.326402
0.259491
0.209611
0.174415
```

```
0.150528
0.135231
0.126718
0.123987
0.126718
0.135231
0.150528
0.174415
0.209611
0.259491
0.326402
0.406306
0.479283
0.509466

];
t1 = [0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
5.5
6
6.5
7
7.5
8
8.5
9
9.5


];% independent vector
t2 = [0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
5.5
6
6.5
7
7.5
8
8.5
9
9.5
```

```
];
figure
hold on % allow all vectors to be plotted in same
% figure
plot(t1,X,'blue')
plot(t1,Y,'red')
plot(t1,Z,'green')


function createfigure(X1, YMatrix1)
%CREATEFIGURE(X1,YMATRIX1)
%  X1:  vector of x data
%  YMATRIX1:  matrix of y data

%  Auto-generated by MATLAB on 04-Jun-2015 05:06:28

% Create figure
figure1 = figure;

% Create axes
axes1 = axes('Parent',figure1);
hold(axes1,'all');

% Create multiple lines using matrix input to plot
plot1 = plot(X1,YMatrix1,'Parent',axes1);
set(plot1(1),'Color',[0 0 1],'DisplayName','900 MHz');
set(plot1(2),'Color',[1 0 0],'DisplayName','1800 MHz');
set(plot1(3),'Color',[0 1 0],'DisplayName','2100 MHz');

% Create xlabel
xlabel({'Distance  X(m)'});

% Create ylabel
ylabel({'Power Density, Pd (W/m2)'});

% Create title
title({'Power Density variation with distance from base station'});

% Create legend
legend(axes1,'show');
```

APPENDIX B

Table 5.1 Power densities and Electric fields obtained for 900MHz for h_0=0m

Table 5.2 Power densities and electric fields obtained for 1800MHz for h_0=0m

Table 5.3 Power densities and electric fields obtained for 2100MHz for h_0=0m

Table 5.4 Power densities and electric fields obtained for 900MHz for h_0=1.5m

Table 5.5 Power densities and electric fields obtained for 1800MHz h_0=1.5m

Table 5.6 Power densities and electric fields obtained for 2100MHz h_0=1.5m

Table 5.7 Power densities and electric fields obtained for 900MHz for h_0=2m

Table 5.8 Power densities and electric fields obtained for 1800MHz for h_0=2m

Table 5.9 Power densities and electric fields obtained for 2100MHz for h_0=2m

Table 5.10 Power densities and electric fields obtained for 900MHz for h_0=4m

Table 5.11 Power densities and electric fields obtained for 1800MHz for h_0=4m

Table 5.12 Power densities and electric fields obtained for 2100 MHz for h_0=4m

Table 5.13 Power densities and electric fields obtained for two sources exposure to 2100MHz

Table 5.14 Power densities and electric fields obtained for two source exposure to 2100MHz for object an object of height h0=2m

Table 5.15 Power densities and Electric fields obtained for exposure to two sources at 2100MHz for an object of height object h0= 1.5 m

Table 5.16 Power densities and Electric fields obtained for exposure to two sources at 2100MHz for an object of height object h0 = 0m

APPENDIX C

List of abbreviations

BTS-Base Transceiver Station/System

CDMA- Code Division Multiple Access

EM- Electromagnetic

EMF-Electromagnetic Field

EMR-Electromagnetic Radiation

GSM-Global System for Mobile Communication

ICNIRP-International Commission for Protection on Non-ionizing Radiation

INIRC- International Non Ionising Radiation Committee

IR-Ionizing radiation

IRPA-International Radiation Protection Association

ITU-International Telecommunications Union

NIR-Non-ionizing Radiation

POTRAZ-Postal And Telecommunications Radiation Authority of Zimbabwe

RF-Radio Frequency

RPAZ-Radiation Protection Authority Of Zimbabwe

SAR-Specific Absorption Rate

WHO-World Health Organisation