Assessment of Electromagnetic Radiation Levels from Selected Mobile Telephones used in Kenya

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A thesis submitted in partial fulfillment for the Degree of Master of Science in Physics in the Jomo Kenyatta University of Agriculture and Technology

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DECLARATION

This thesis is my own original work and has not been presented for a degree in any other University.

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DEDICATION

To all mobile phone users, you will find in this thesis useful insights that can be helpful in mitigating radiation exposure from mobile phones.

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LIST OF ABBREVIATIONS

Technical Abbreviations

APC	Adaptive Power Control
AuC	Authenticating Centre
BGR	Background Radiation
BSC	Base Station Controller
BTS	Base Transceiver Station
CDMA	Code Division Multiple Access
DNA	Deoxyribonucleic Acid
DTX	Discontinuous Transmission
EIR	Equipment Identifier Register
EMF	Electromagnetic Field
EMR	Electromagnetic Radiation
EMW	Electromagnetic Wave
HLR	Home Location Register
HUT	Handset Under Test
IMEI	International Mobile Equipment Identity

IMSI	International Mobile Subscriber Identity
LCD	Liquid Crystal Display
LFR	Low Frequency Radiation
ME	Mobile Equipment
MS	Mobile Station
MSC	Mobile Service switching Centre
MSISDN	Mobile Station Integrated Services Digital Network Number
MSRN	Mobile Station Roaming Number
NIR	Non-Ionizing Radiation
RF	Radiofrequency
SAR	Specific Absorption Rate
SIM	Subscriber Identity Module
SWR	Standing Wave Ratio
TAC	Type Allocation Code
TDMA	Time Division Multiple Access
USB	Universal Serial Bus
VLR	Visitor Location Register

Organization Abbreviations

ANSI	American National Standards Institute
ATMR	Africa Telecom Market Report
AWC	African Wireless Communications (Yearbook)
BASCAP	Business Action to Stop Counterfeiting and Piracy
CCK	Communications Commission of Kenya
CEC	Commission of European Committee
CENELEC	European Committee for Electrotechnical Standardization
CEPT	Radiocommunications Committee within the European Conference of Postal and Telecommunications Administrators
FCC	Federal Communications Commission (USA)
FDMA	Frequency Division Multiple Access
GSMA	GSM Association
ICNIRP	International Commission on Non-ionizing Radiation Protection
IEEE	Institute of Electrical and Electronics Engineers
IEGMP	Independent Expert Group on Mobile Phones
ITU	International Telecommunications Union
JKUAT	Jomo Kenyatta University of Agriculture and Technology

KeBS	Kenya Bureau of Standards
NEMA	National Environmental Management Authority
OECD	Organization for Economic Cooperation and Development
OSHA	Occupational Safety and Health Administration (USA)
RPB	Radiation Protection Board (Kenya)
STUK	Radiation and Nuclear Safety Authority (United Kingdom)
WHO	World Health Organization

General Abbreviations

1G	First Generation
2G	Second Generation
3G	Third Generation
GSM	Global System for Mobile communications
GPS	Global Positioning System
INP	International Numbering Plan
IMTS	Improved Mobile Telephone Service
NBM	*Narda* Broadband RF meter
NFP	Net Facility Provider

LIST OF SYMBOLS

Symbol	Name	Unit
$\boldsymbol{B}$	Magnetic field strength	Ampere per meter (Am^{-1})
$\boldsymbol{E}$	Electric field strength	Volts per meter (Vm^{-1})
$\boldsymbol{I}$	Intensity of radiation	Watts per square meter (Wm^{-2})
$\boldsymbol{V}$	Potential difference (Voltage)	Volts (V)
$\boldsymbol{\sigma}$	Conductivity of the tissue	Siemens per meter (Sm^{-1})
$\boldsymbol{\rho}$	Density of the tissue	Kilograms per cubic meter (kgm^{-3})
$\boldsymbol{D}$	Diameter (maximum dimension) of antenna	Meter (m)
$\boldsymbol{e}$	Efficiency of antenna	%
$\boldsymbol{\eta}$	Efficiency of anti-radiation filter	%
$\boldsymbol{P_r}$	Radiated power	Watts (W)
$\boldsymbol{G}$	Antenna gain	decibels (dB)
$\boldsymbol{Z}$	Impedance	Ohm (Ω)
$\boldsymbol{h}$	Planck's Constant	Joules -second (J.s)
$\boldsymbol{\lambda}$	Wavelength of RF signal	Meter (m)
$\boldsymbol{\upsilon}$	Frequency of RF signal	Hertz (Hz)
$\boldsymbol{\Gamma}$	Antenna's reflection coefficient	
$\boldsymbol{k}$	Dielectric constant	
$\boldsymbol{A_e}$	Antenna factor	
$\boldsymbol{C_f}$	Calibration factor	

ABSTRACT

The use of mobile phones in Kenya has escalated in the recent past. This has increased the general population exposure to mobile phone radiation. Numerous mobile phone manufacturers, producing different handset models with varying qualities, have also emerged. Consequently, this has raised many concerns over the level of the radiation transmitted from these devices as well as the effect of their physical condition under different exposure conditions, and the effectiveness of anti-radiation filters in suppressing the said emissions. In this regard, the intensity of radiation around various GSM phones has been measured using broadband radiofrequency meter and spectrum analyzer, and the results assessed based upon the established international safety standards on non-ionizing radiation. The radiation levels from the 22 selected mobile phones ranged from 0.0113 to 0.4669 $mWcm^{-2} \pm 5.773\times10^{-5}$ $mWcm^{-2}$ with the highest from Nokia Series N95 and lowest from Nokia 1110. These radiation levels are all within the FCC recommended exposure limits, and only N95 is above ICNIRP reference level. It has further been established that high radiation intensities from a transmitting handset appear between the dial and reception of a call. The use of different anti-radiation filters in abating mobile phone radiation has also been found effective, but with different degrees of efficiencies of which none meets the 99% efficiency asserted by the respective manufacturers. It has also been established that the radiation levels

from a mobile phone are affected by the physical condition of the body. The intensity of radiation from a naked handset, for instance, was found to be higher than that of a well covered handset. Only 20% of the mobile phones under study were compliant to the regulations regarding the International Mobile Equipment Identity (IMEI); 80% of handsets were however found to contravene such standards.

CHAPTER ONE

1.0 INTRODUCTION

1.1 General background

The mobile communication industry in Kenya is experiencing rapid growth. This is a direct consequence of a high rate at which cellular technologies are transcending the world and consequent increase in economic activities. Some of the profound applications of mobile phones include voice and data communication as well as money transfer and mobile banking services such as *m*-pesa, zap, yu-cash, orange money and *m*-kesho. New products are being introduced almost daily into the industry and these have gained general-public acceptance and attracted enormous investment opportunities.

The significant reduction of call charges and costs of mobile phone handsets, and the growth of mobile penetration in Kenya has fueled increase of the number of subscribers. Currently, there are about 19.4 million mobile phone subscribers in Kenya (CCK, 2010a) and this is expected to rise to 29.28 million, or 66.7% penetration, by the year 2013 (ATMR, 2009; ITU, 2009). The growth of mobile telecommunication industry that is being witnessed in Kenya reflects a similar trend across the world.

The Communications Commission of Kenya (CCK) is the government's regulatory body of the telecommunication industry. It allocates basic frequency spectrum to all mobile phone operators. At present, there are four cellular mobile service providers: Safaricom, Airtel (formerly Zain), Orange and YU under the category of the Network Facility Provider (NFP) in a unified licensing framework, commanding 80.25%, 12.11%, 4.27% and 3.37% subscriber-market potential respectively (CCK, 2010a; AWC, 2010). These mobile operators use Global System for Mobile communication (GSM) or Second Generation (2G) technology, and are advancing towards adapting the Third Generation (3G) technology.

To support and guarantee ubiquitous connectivity for all subscribers, the mobile operators have massively rolled out and constructed many base stations countrywide. Currently, there are about 4000 base stations in Kenya (RPB, 2008). The extensive use of mobile phones and installation of base stations raises the question of whether there are implications for human health.

1.2 Contribution of mobile telephony to the socio-economic development in Kenya

Mobile phones have brought a paradigm shift in the corporate world and various innovative technologies for the users. They are improved entertainment and access to information such as internet access.

The mobile phone sector has also employed approximately 3.5 million people, directly and indirectly from technical fields such as engineers, administrators, mobile charging services, money transfer services, sales-outlets, and customer service centers distributed across the country. Arunga and Kahora (2007) have also shown that the sale of prepaid recharge vouchers and mobile telecommunication accessories is evidently everywhere as opposed to other forms of businesses, an indication of high penetration. All these activities help to generate more cash in extra revenue for the operators. This has helped spread the wealth to those who do not have the benefit of formal education or establishment.

Mobile communication has also helped in managing and coordinating emergency cases such as road traffic accidents, infernos, robbery and crime. It has become of great importance in law enforcement, tracking of illegal activities, and in providing evidence for convictions and acquittals. The information found in mobile phones has great potential for use as evidence in criminal investigations. The mobile industry is also the leading source of government revenue through taxation and investment in the country. In 2009, the sector remitted KSH 84.2 billion as the total mobile annual revenue to the government of Kenya, accounting for an increment of 15.9% compared to the previous year. Investments have also increased by 19.5% during this same period (CCK, 2010a).

1.3 Mobile phone networks and communication

Mobile phones communicate within or across the network(s) over base transceiver station (BTS) through wireless interface using electromagnetic radiation. The BTS is responsible for transmission and reception of radiofrequency signals (Rogier, 2006). Each of the BTS handles a limited number of subscribers at a time at any particular instant and covers a limited geographical region. In order to achieve wide network coverage, the mobile operators have to establish a base station system or networks across the country, with more installations in densely populated areas such as cities and towns (IEGMP, 2000). The network coverage in major towns in Kenya is well established, but some rural areas especially North Eastern Province are still being networked (CCK, 2008a).

Communication over the network requires the mobile phone handset to be activated. An activated handset, also called mobile station (MS), is logically made up of mobile equipment (ME) and subscriber identity module (SIM) as shown in Figure 1.1.

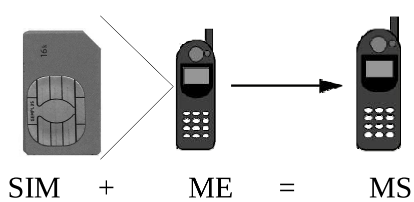


Figure 1.1: Components of mobile station (activated handset) (Rogier, 2006)

The ME is the mobile phone handset or terminal, excluding SIM card; and SIM is the chip embedded in the SIM card to identify the subscriber in the network. When the SIM card is inserted in the ME, the subscriber may register with the network. The SIM card contains information such as International Mobile Subscriber Identity (IMSI) and operator-specific emergency number (Schiller, 2003). In a bid to curb crime, the government of Kenya has recently legislated SIM registration (CCK, 2010b). Each handset unit in the GSM network is identified using the International Mobile Equipment Identity (IMEI), a unique 15-digit number that is hard-coded in ME and cannot be modified (GSMA, 2007).

In this work, the intensities of radiofrequency radiation from selected mobile phones are investigated and assessed based on the internationally established standards on non-ionizing radiation. Recommendations arising from this study are also presented so as to call into play further studies and appropriate measures.

1.4 Statement of the problem

Although the measurement and assessment of electromagnetic fields has been done on a few selected handset models (Usman *et al.*, 2009; Usikalu and Akinyemi, 2007; Damir *et al.*, 2004), little is known about some of the handsets that have been introduced in the Kenyan telecommunication market. Some of these phones are counterfeits of the originals and therefore their quality and reliability are not guaranteed nor is there full provision of information concerning them (BASCAP, 2009). Despite the known low quality nature of these devices, they still find their way into the country owing to economic disparity of the society to cater for the low end public needs (OECD, 2007). This may lead to the problem of electronic-waste (NEMA, 2010) and unwarranted exposure of the general-public to RF radiation and the effects thereof (discussed in Section 2.1 & 2.2).

Besides furthering the scope of radiation levels from various handsets, the present study assesses the quality of these devices for compliance to the established standards on non-ionizing radiation (NIR) and international mobile equipment identifier (IMEI). In this study, measurement of background and mobile phone radiation levels is carried out using broadband RF meter and spectrum analyzer. A dosimetric assessment of RF radiation before and after installing different anti-radiation filters is also performed. This gives a basis of examining the effectiveness of these filters in reducing RF radiation incident on the users.

1.5 Research objectives

The primary aim of this study was to measure and assess radiation intensities from different commonly used mobile phone models in Kenya so as to determine their compliance with human safety standards on non-ionizing radiation.

This has been done by looking at the following specific objectives:

(i) To measure electromagnetic radiation intensities from various mobile phone models and assess the results based upon the established standards on non- ionizing radiation.

(ii) To use anti-radiation filters on selected phone models to establish the degree of effectiveness of the filters in reducing the emitted radiation.

(iii) To determine and assess how the rear body/battery cover of a handset affects radiation levels.

(iv) To assess various mobile phones for compliance to the international mobile equipment identity (IMEI) standards and its relation to radiation levels.

1.6 Significance of the study

This study seeks to determine whether the electromagnetic radiation (EMR) levels from mobile phones adhere to the specified radiofrequency (RF) exposure limits on non-ionizing radiation. This is essential for general-public safety and effective protection. It can also help to allay unfounded anxiety on some unbranded phones and give reassurance of mobile phone radiation exposure levels in Kenya. It will also be useful in identifying and curbing the importation and use of sub-standard cell phones into the country.

The assessment of the mobile phone radiation intensities will provide the telecommunications regulator and national standards body with clear guidelines on NIR, in line with the safety standards, to fine tune existing policies to suit the emerging trends in the industry. This will further help in the process of regulation, installation of new communication facilities and decommissioning of cellular facilities upon non-compliance with the set standards. It will also enable the enactment of the appropriate and informed checks on the use of mobile phones.

CHAPTER 2

2.0 LITERATURE REVIEW

2.1 Health effects of RF radiation from base stations

A study conducted in Singapore by Sin-Eng and Jit-seng (2000) shows that fatigue, headache, sleep disruption and loss of memory are some of the major health effects that face the people living within 300 m from the base stations. These results concur with previous studies conducted by Baranski and Czerski (1976), Frey (1998) and WHO (2000). In 2002, Hutter *et al.* found cardiovascular symptoms and perpetual speed in cognition; a study that conclusively indicated that the effects of very low but long lasting exposures to emissions from mobile telephone base-stations on well-being and health could not be ruled out. Besides these findings, Maneesh *et al.* (2009) have also determined nausea.

An epidemiological study in occupational settings, conducted by Anita (2005), has further indicated a possible increase in the risk of deoxyribonucleic acid (DNA) mutations. Changing of performance of neurobehavioral functions of office workers working near the base stations has been established by Abdel (2006). Moreover, he found the effect on many symptoms such as the prevalence of neuropsychiatry symptoms, were 22.5% of headache, 38.2% of memory change, 18.8% of dizziness, 9.4% of tumors, 21.7% of depressions symptoms, and 23.5% of sleep disturbance.

A study in the habitats near the base stations, by Santini *et al.* (2003), found that the habitants within 200-300 m area has fatigue; 100-200 m has a headache, sleeping disturbance and nausea; and less than 100 m has irritable moods, depression, forgetfulness, dizziness and lowering of libido. Habitats near the mobile phone base stations have also been investigated by Roosli (2004) who also reported such symptoms: 58% of sleep disturbance, 41% of headache, 19% of depression, 18% of fatigue and 16% lack of concentration.

Hutter *et al.* (2006) have also studied the relationship of illness and distance from the base station. In this study, a maximum electromagnetic field (EMF) (0.05 mWm^{-2}) in the rural area set-up within a radius of 24-600 m from base station was determined. In urban area, within 20-250 m, the maximum EMF was 0.02 mWm^{-2}, and headache, numbness at the hands and feet and lack of concentration were found.

2.2 Health effects of mobile phone radiation

Fröhlich (1980) has attributed the vulnerability and sensitivity of some of the biological electrical activities like metabolism to interference from GSM radiation. Experimental evidence consistent with the effects of ultralow-intensity microwave radiation of a specific frequency on processes such as cell division has since been exhibited by Grundler and Kaiser (1992).

Jensen and Rahmat (1995) have shown that the absorption of RF energy by the human body is made possible by the tissue's water content. Just as a microwave oven can heat and cook meat, the power from a closely held cell phone may affect brain tissue if the head is exposed to the cell phone radiation for extended periods of time (Baumann *et al.*, 2006). These effects are however not taken into account in current safety guidelines (ICNIRP, 1998), which simply restrict the intensity of the radiation to prevent tissue heating in excess of what the body's thermoregulatory mechanism can cope with.

Sandström *et al.* (1998) also reported that RF energy from mobile phones leads to a stinging sensation and a feeling of heat in the facial skin. According to Hyland (2000), the amount of heat generated in a living organism because of exposure to mobile phone radiation depends primarily on the dissipated power density once it has penetrated the system as well as the electrical properties of the bio-matter and efficiency of the body's thermoregulation mechanism. He also found that these disorders are provoked by temperature rise under acute exposure conditions. The extent of such heating would depend on frequency of the radiation as well as the duration of exposure and efficiency of heat dissipation. In this respect, Usikalu and Akinyemi (2007) have since observed that this poses a possibility of localization of hot spots or energy deposition in the brain due to internal reflections.

Investigation of the incident RF field especially when the antenna is in front of the head, which is the most typical configuration related to the use of mobile phones, done by Moneda *et al.* (2003), has further verified that the eyes, despite their small volume, absorb considerable amounts of this energy and thus resulting in cataract formation and blurred vision.

In the recent past, many of the concerns people have had about RF exposure has been its connection with cancer. In 1970, Steve Haltiwanger did establish the electrical properties of cancer cells. In Steve's monograph, the nature of electromagnetic fields from RF sources are explicitly analyzed, compared and correlated to those found in a typical animal cell as well as cancer cell. Damijan *et al.* (2006) has since expanded Steve's scope by promulgating the equations that relate the electrical properties of tissues and cell suspensions.

Lohn *et al.* (2004) found that the overall odds ratio for acoustic neuroma associated with regular use of mobile phone was 1.0 (95% confidence interval = 0.6 – 1.5). Ten years after the start of mobile phone use the estimated relative risk increased to 1.9 (0.9 – 1.4); when restricting tumors on the same side of the head as the phone was normally used, the relative risk was 3.9 (1.6-9.5). Maneesh *et al.* (2009) and WHO (2009) have also, respectively, linked the reduced sperm counts and brain cancer to RF exposure. These conditions are aggravated due to low supply of blood to these organs.

2.3 Measurement of RF energy around mobile phones

Damir *et al.* (2004) measured RF power density for selected Nokia phones using "Netmonitor" software, Anristu MS2661C spectrum analyzer and dipole antenna. Measurement results were compared with the calculated values and standard exposure limits on non-ionizing radiation. In 2007, Usikalu and Akinyemi investigated the possible presence and intensity of RF radiation from ten (10) different mobile phone handset models at a distance of less than 20 cm. The mobile phones in their study were Nokia 1100, 3210, 3310, 1112, 8310; Sagem My X1, My X5, My 100X; Siemens MC60 and Sony Erickson Z530i. A cell sensor that is optimized to measure RF and extremely low frequency radiation was used. Of the ten handsets under study, Nokia 1100 and Sagem My X5 were the highest transmitting handset (0.45 $mWcm^{-2}$), whereas the least transmitting being Sagem My X1. All the measured values were within the safe limits set by U.S. Federal Communications Commission (FCC), 0.6 $mWcm^{-2}$ (Barnes, 1999).

Recently, Usman *et al.* (2009) conducted a study on near fields EMR from different mobile telephones in active mode using a tri-axis isotropic probe and electric field meter. According to Usman *et al.* (2009), the EMR levels of some mobile telephones were found to be lower and others higher than the International Commission on non-ionizing Radiation (ICNIRP) (1998) guidelines for exposure to general-public. It was further shown than RF intensity depends on the operation and proximity of the mobile phone to the user; the safest mode of operation was determined to be the SMS mode.

CHAPTER THREE

3.0 THEORETICAL CONSIDERATIONS

3.1 Introduction

This chapter defines and discusses various terms used in electromagnetic, and specifically those involved in mobile telephony and exposure assessment. It first gives an exposition into the history of mobile telephony, the basic parts of the mobile telephone as well as its operation principles in the GSM network. In addition to the power density of RF fields, anti-radiation filters that suppress these fields and the various exposure safety standards are also highlighted.

3.2 History of mobile telephony

The history of mobile telephony traces its roots from the ancient means of wireless communication such as the use of smoke signals, light and drums. It was not until 18th century, when Claudde Chappe invented the optical telegraph (1794) (Agar, 2003), that long-distance wireless communication was made possible with technical means. The discovery of electromagnetic waves and equipment to modulate them formed the basis for wireless communication.

In 1831, Michael Faraday demonstrated the concept of electromagnetic induction and in 1864 James C. Maxwell laid the theoretical foundation for electromagnetic fields with his famous equations (Jackson, 1975). In 1886, Heinrich Hertz demonstrated the wave character of electrical transmission in space, which proved Maxwell's Equations. It was not until 1893 that Nikola Tesla demonstrated in details the principles of wireless telegraphy. In December 1901, Guglielmo Marconi (1874-1937) established a wireless communication, between Britain and the United States, which earned him the Nobel Prize in Physics in 1909 (which he shared with Karl Braun) (Agar, 2003).

In 1908, Nathan B. Stubblefield of Murray- Kentucky patented a wireless telephone which he applied to "cave radio" telephones. Huge antennas and transmission power were needed to send and receive the signals (Agar, 2003). However, introduction of cells for mobile phone base stations was invented in 1947 by Bell Labs engineers who also further developed them during the 1960s (Schiller, 2003).

In 1964, Bell Labs introduced Improved Mobile Telephone Service (IMTS), a replacement to the badly aging Mobile Telephone System, which operated on half-duplex basis. IMTS worked in full-duplex, so people did not have to press a button to talk. It enabled automatic subscriber identification rather than by spoken exchange between caller and operator which was evident in preceding systems (Schiller, 2003).

Cellular phone technologies have since evolved from analog (1G) to digital (GSM i.e. 2G) phones and most recently, the 3G phones (smartphones) (CCK, 2008b). Most of these smartphones have increased bandwidth coupled with high data transfer rates and provide the convenience of using two SIM cards at the same time as well as multimedia services, Bluetooth, touch screen, multiple speakers, expandable memory slots, camera, WiFi enabled and GPS capabilities.

3.3 Parts of a mobile telephone

The main parts of a mobile telephone include a circuit board, an antenna, liquid crystal display (LCD), keyboard, microphone, speaker and battery (Duff, 1976).

A circuit board has three types of chips: analog-to-digital and digital-to-analog conversion chips, digital signal processor and microprocessor. Analog-to-digital converter translate the outgoing audio signal from analog to digital form while digital to analog converter changes the incoming signal from digital back to analog. A circuit board can process millions of calculations per second in order to compress and decompress the voice stream. Digital signal processor performs signal manipulations at a high speed. The microprocessor handles all the main functions for the keyboard and display, deals with command, control signaling with the base station, and coordinates the rest of the functions on the board. Read-only-memory and flash memory chips provide storage for the phone's operating system and customizable features such as the phone directory.

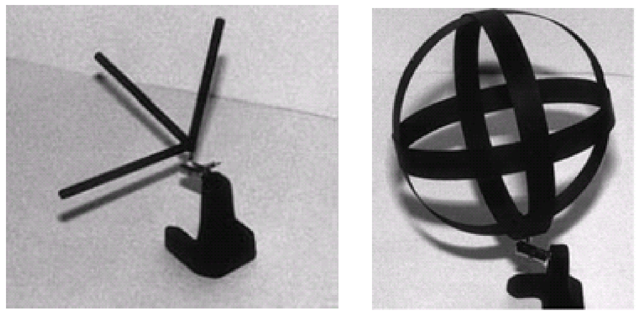
Radiofrequency and power section handles power management and recharging, and deals with the hundreds of FM channels (Marshall, 2002). The antenna does detection of radiated signals (electromagnetic energy). Antennas can also be used to receive (capture) or transmit electromagnetic energy travelling through space (Balanis, 2005). These antennas are installed in all mobile phone handsets and base transceiver stations (BTS).

3.4 Antennas

3.4.1 Introduction

An antenna is a device that is used to transmit/receive electromagnetic waves (signals) in an unbounded medium, usually free space. They are frequency dependent devices, and thus reject signals beyond their operating frequencies. Antennas are very essential parts in any communication system (Kinsk, 2006).

The basic antenna types for electric field $\vec{E}$ and magnetic field $\vec{B}$ measurements are a *single electric field antenna element* and *pick-up loop*. The most frequently used antennas are **non-isotropic** (Figure 3.1a), and consist of three orthogonal elements with the outputs joined together to give a combined output which can be shown to correspond to the average value of the sum of all the impinging RF energy components. They however cannot provide phase information (Kitchen, 2001).



a) Non-Isotropic b) Isotropic

Figure 3.1: Antenna types (Durney et al., 1986)

A *single element* will only respond to the polarization corresponding to that of the source, for example with electric field measurement, when the electric field element is parallel to the source electric field. Such antennas are known as **non-isotropic** (Figure 3.1b), i.e. they do not respond to all the energy in a field containing signals with more than one, such as that which involves reflections from local conductive objects including the ground, or to the elliptical polarization in the near field. As a result, they will not give an indication of the total field present (Durney *et al.*, 1986).

3.4.2 Basic parameters of antennas

The basic parameters that affect antennas' performance are: frequency band of operation (bandwidth), polarization, input impedance, gain, radiation patterns and efficiency (Kinsk, 2006; Schiller, 2003).

As EMW travel from the source to the antenna through a medium (space), they encounter differences in impedance at each interface. The ratio of the maximum to minimum power in the wave, i.e. standing wave ratio (SWR), can be determined. Minimizing impedance differences at each interface reduces SWR and maximizes power transfer through each part of the system. The frequency response of an antenna at its port is defined as input impedance Z_{in} (i.e. the ration between voltage and currents at the port of the antenna). The antenna's reflection coefficient Γ and return loss R_L, given in Equation 3.1 and 3.2 respectively (Kinsk, 2006).

$$\Gamma = \frac{Z_{in} - Z_0}{Z_{in} + Z_0} \tag{3.1}$$

$$R_L = -20 \ \log|\Gamma| \tag{3.2}$$

where,

Z_0 = Normalizing impedance at the port

Z_{in} = Input impedance of the port

R_L = Return loss

The *radiation pattern* is the distribution of radiated energy from an antenna over a surface of constant radius centered upon the antenna, as shown by 3D diagram in Figure 3.2. Some energy is inevitably radiated in other directions with lower levels than the main beam where most of the power is radiating (Kitchen, 2001).

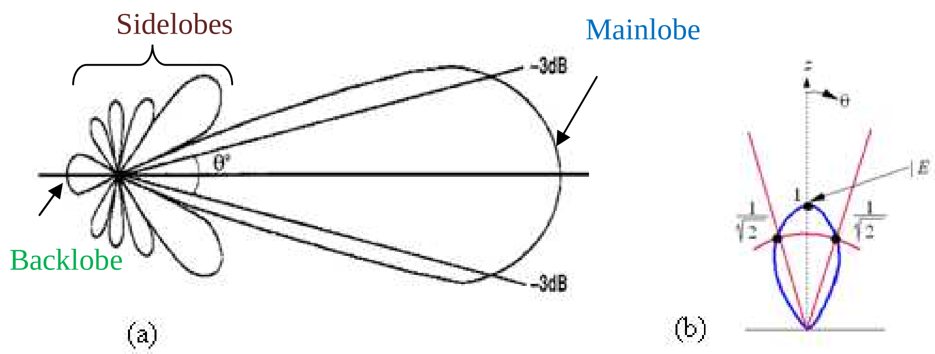


Figure 3.2: Radiation pattern (characteristics) (Kitchen 2001)

From the peak radiation intensity in Figure 3.2, which is the peak of the main-lobe, 3 dB reduction corresponds to the half power value, i.e. a reduction of power density by a factor of two relative to the axis and a corresponding reduction of the magnetic and electric fields by the square root of that factor, i.e. $\sqrt{2}$. The term 'beamwidth' refers to the width in degrees of angle between the opposite points corresponding to a 3dB reduction in power density relative to the axis (Balanis, 2005; Durney *at al.*, 1986).

Polarization of an antenna is the orientation of electric field $\vec{E}$ of a radio wave with respect to the earth's surface. This polarization can be linear or circular. In linear polarization, the antenna compels $\vec{E}$ to a particular direction i.e. horizontally or vertically; hence the terms horizontal and vertical polarization. In circular polarization, the antenna continuously varies $\vec{E}$ through all its possible values of its orientation with respect to the earth's surface. Circular polarization is classified as right-hand polarized or left-hand polarized using a "thumb in the direction of propagation" rule (Kinsk, 2006).

Antenna efficiency e is the measure of antenna's efficiency to transmit the input power into radiation, see Equation 3.3 (Balanis, 2005).

$$e = \frac{P_r}{P_{in}} \tag{3.3}$$

where,

P_r = radiated power; and P_{in} = input power.

The *directivity* of an antenna, the ratio of radiation intensity in a given direction from the antenna to the radiation intensity averaged over all direction, is given in Equation 3.4 (Kinsk, 2006).

$$D = \frac{I_a}{I_s} = \frac{4\pi I_a}{P_r} \tag{3.4}$$

where:

D = Directivity of antenna

I_a = Radiation intensity of antenna

I_s = Radiation intensity of isotropic source

Antenna gain G, shown in Equation 3.5, is directly related to directivity. It takes into account directional capabilities as well as efficiency (Kinsk, 2006). Moreover, *antenna factor* A_e is defined by Equation 3.6 (Duff, 1976).

$$G = \frac{4\pi I_a}{P_{in}} \tag{3.5}$$

$$A_e = \frac{P_r}{I_a} = \frac{G\lambda^2}{4\pi} \tag{3.6}$$

3.4.3 Power density and radiated power

Generally, for an antenna radiating into free space, two distinct regions can be identified where the behavior of the EMFs from the antenna displays specific characteristics i.e. near-field and far-field region – as shown in Table 3.1.

Table 3.1: Measurement parameters at different distances from EMR source (CEPT, 2004)

	Near field		Far-field region
	Reactive near-field region	Radiating near-field region	
Lateral edge of the region, measured from the antenna	$0 < r < \lambda$	$\lambda < r < \frac{2D^2}{\lambda}$	$\frac{2D^2}{\lambda} < r < \infty$
E ⊥ B	No	Quite Yes	Yes
$Z = \frac{E}{B}$	$\neq Z_0$	$\approx Z_0$	$= Z_0$
Components to be measured	*E* and *B*	*E* or *B*	*E* or *B*

where,

r = the distance from the radiating source;

λ = wavelength of EM signal;

D = maximum dimension (diameter) of antenna.

In the **near-field region** (i.e. radiating and reactive near-field regions), $\vec{E}$ and $\vec{B}$ do not have substantial plane-wave characteristics, but vary considerably from point to point. As the distance from the transmitting source increases (**far-field region**), $\vec{E}$ and $\vec{B}$ oscillate at right angles both to each other and to the direction of propagation.

Therefore, the fields are in phase, so that the point at which $\vec{E}$ is greatest coincides with the point at which $\vec{B}$ is greatest and are mathematically interdependent as shown in Equation 3.7 (ICNIRP, 1998).

$$P_r = \frac{E^2}{Z_0} \quad (3.7a)$$

$$P_r = Z_0 B^2 \quad (3.7b)$$

where,

E = magnitude of electric field (Vm^{-1})

B = magnitude of magnetic field (Am^{-1})

P_r = Radiated power (W)

Z_0 $(= 377\ \Omega)$ = the characteristic impendence.

The intensity of radiation of an electromagnetic wave is the power passing through a unit surface area, normal to the direction of wave propagation (IEGMP, 2000). The variation of intensity with distance from a transmitting source is shown in Figure 3.3.

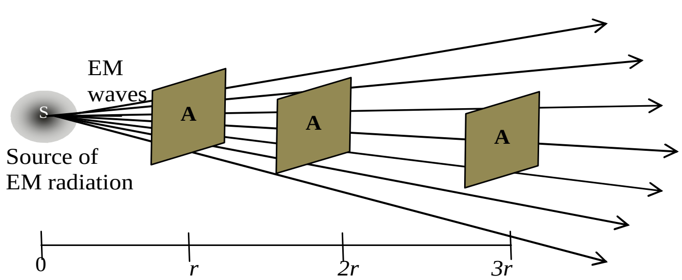


Figure 3.3: Change of intensity with distance from the transmitting source (Pederson and Anderson, 1999).

In Figure 3.3, the given square surface *A* at distance *r* is being hit by energy radiating from the source *S*; As *A* moves farther away from the source, less energy (fewer lines) hit the same surface area. The distance between the radiating source and intercepting surface determine the surface area exposed to RF energy (Pederson and Anderson, 1999).

Considerable amount of electromagnetic energy is concentrated near the source and is inversely proportional to the square of distance, hence the inverse square law given in Equation 3.8 (Kitchen, 2001).

$$I = \frac{P_r G_0}{4\pi r^2} \tag{3.8}$$

where:

I = intensity of the electromagnetic radiation;

P_r = radiated power (W);

r = distance from the radiating source (antenna);

G_0 = maximum gain.

In Equation 3.8, the intensity of radiation exposure decreases from the source. Thus maximum intensity is absorbed next to the ear or the head of the mobile phone user (Chen and Lin, 2007; Goiceanu and Dănulescu, 2006).

3.4.4 Typical antenna systems

Various typical antenna systems are shown in Figure 3.4. Omni-directional antennas are used where all-round network coverage is needed, and sectored antennas are used whenever a network restriction to a particular angular coverage (in an elevation) of some nominal amount such as 45°, 60°, 90°, 120° etc is needed. An alternative type of sector antenna system is the use of yagi antennas (similar to domestic TV antennas in appearance) stacked in vertical or horizontal banks to achieve the desired coverage (Kitchen, 2001).

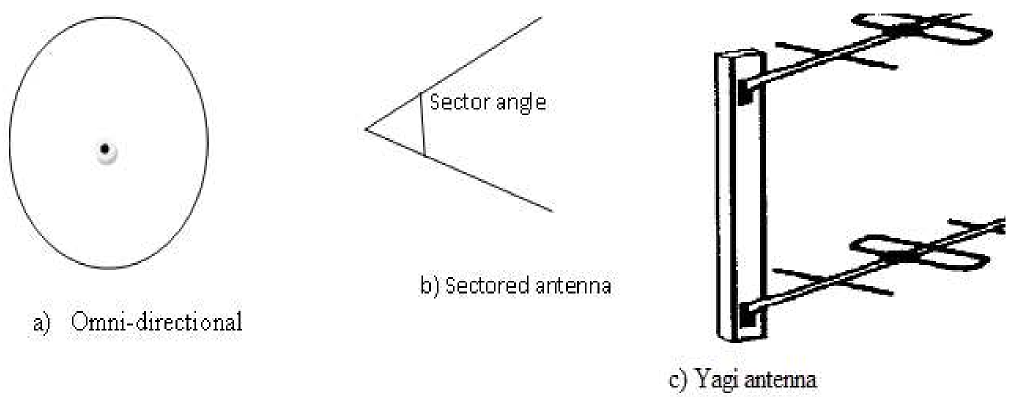


Figure 3.4: Antennas: (a) Omni-directional (b) sectored (c) Yagi (Kitechen, 2001)

3.5 Mobile phone in the GSM network

3.5.1 Architecture of GSM network

The architecture of the GSM network is shown in Figure 3.5. The Mobile Station (MS) consists of the Mobile Equipment (ME) and the Subscriber Identity Module (SIM). The ME, commonly referred to as a terminal or handset, comes in two varieties: fixed and portable. A fixed ME is usually installed (e.g. in a vehicle or office) while portable MEs are normally carried by subscribers. Due to size limitations and power requirements, fixed MEs were originally predominant though this situation has changed drastically in recent years as the portable ME is by now almost ubiquitous and even regarded as a fashion accessory. The ME is uniquely identified by its IMEI, a number that is primarily used for security purposes.

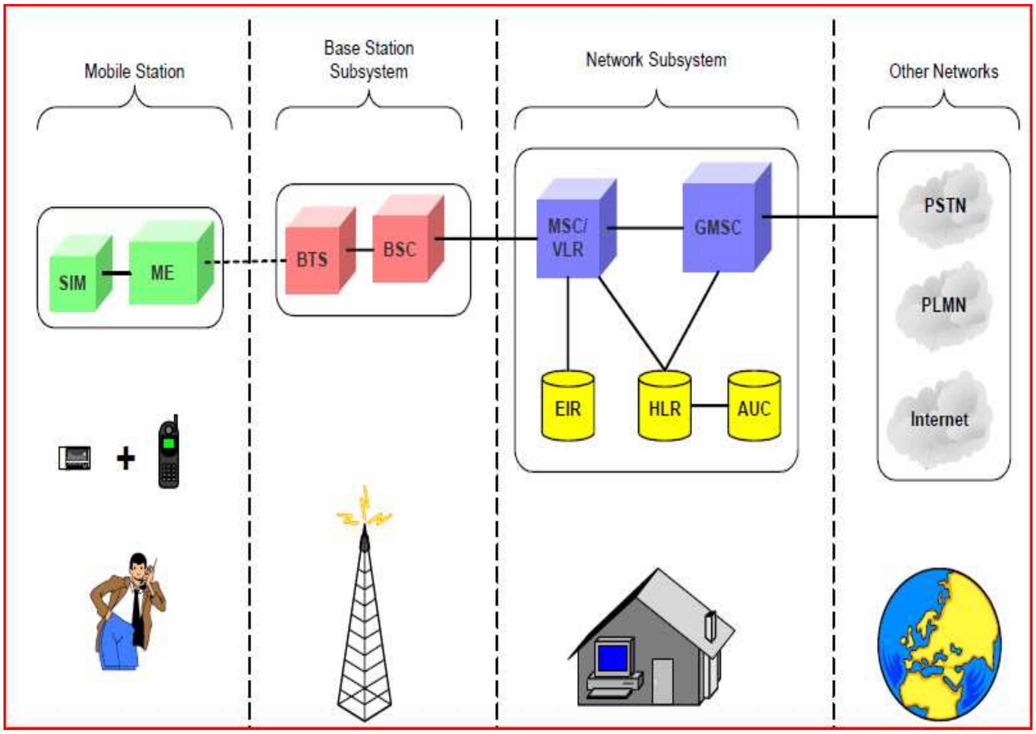


Figure 3.5: Architecture of GSM network (Schiller, 2003)

A **Subscriber Identity Module (SIM)** is a smartcard that is inserted into the ME to provide personal mobility. Each SIM card contains an IMSI, a number that uniquely identifies the subscriber to the network thereby allowing access to subscribed services. To prevent unauthorized access, the SIM card can be protected using a Personal Identification Number (PIN). Only emergency calls can be made from a terminal without a SIM card. While the SIM card currently facilitates a number of services including the standard Short Message Service (SMS), advances in smartcard technologies will ensure that the SIM card becomes a cornerstone for any new services deployed in the future (Gianluigi and Alessandro, 2008).

The **Base Transceiver Station (BTS)**, or simply the base station, is the interface for the MS to the network. It handles all communications with the MS via the air interface (technically referred to as Um interface). Essentially, the transmitting power of a BTS defines the cell size i.e. its network coverage area. In large urban areas, the number of BTSs deployed is large so the corresponding cell size is small. In contrast, there is usually a far smaller number deployed in rural areas so the cell size can be quite large (Schiller, 2003).

The **Base Station Controller (BSC)** controls a number of base transceiver stations through a wireless interface referred to as the Abis interface. It allocates and releases of radio channels responsible for handover management when a mobile station roams into an area covered by another BSC. The BTS and BSC form the Base Station Subsystem (Rogier, 2005).

The nerve centre of the entire GSM network is called Network Sub-System. It manages all call processing and subscriber related functions. Besides the core-switching component, it contains a number of databases and gateways to other networks (i.e. Public Switching Telephone Network (PSTN) and Public Land Mobile Network (PLMN)) (Schiller, 2003).

The **Mobile Service-switching Centre (MSC)** performs all switching/exchange functions and handles registration, authentication as well as location updating. A GSM network has more than one MSC and may connect to other networks using Gateway MSC (GMSC).

Home Location Register (HLR) stores administrative information for all subscribers. This information include IMSI number, actual phone number, permitted supplementary services, current location and parameters for authentication and ciphering. There is one HLR per GSM PLMN.

Visitor Location Register (VLR) contains data on all MSs currently in the area served by the MSC. It has permanent subscriber's data (identical to that in HLR). It is consulted during call establishment and caller authentication. VLR is usually integrated with MSC so that geographic area covered by both coincides; signaling requirements are thus simplified considerably (Rogier, 2005).

Authentication Centre (AUC) is a protected database, which stores all algorithms used for authentication purposes. It knows the resources or rights, which have been issued to the subscriber (stored on SIM card), and provides HLR or VLR with parameters for completing authentication (Atique, 2005).

Equipment Identity Register (EIR) maintains lists of IMEIs of all valid and invalid equipment for the network. An IMEI may be invalid if stolen, not approved for use on the network and possibly due to some defect. An EIR is consulted during registration or call setup. Depending on IMEI number, EIR categorizes the equipment into black list, grey list or white list. Blacklisted mobile phones are those with invalid IMEIs, reported stolen or whose operation on the network will adversely affect network operation. These mobiles will not be allowed to access the network. Grey-listed handsets are non-conforming or have uncertain IMEIs, but may be used on the network. The white list contains IMEIs of GSM handsets that conform to requirements set down by the network operator (Schiller, 2003).

3.5.2 International mobile equipment identifier

International mobile equipment identifier (IMEI) is a unique code that corresponds to a specific handset in GSM network, and automatically identifies the manufacturer and model of the mobile equipment (ME). It is hard-coded on the compliance plate under the battery or displayed on the screen by dialing *#06# (Schiller, 2003). All the IMEIs in the GSM network are stored in an Equipment Identity Register (EIR) (Paul, 2005). The EIR has become a regulatory requirement for mobile phone operators in many countries.

The structure and format of IMEI is shown in Figure 3.6. Of the 15 decimal digits of IMEI, the initial 8-digit portion is known as the Type Allocation Code (TAC); the remainder of the IMEI is serial number (SNR) and a Luhn check digit at the end.

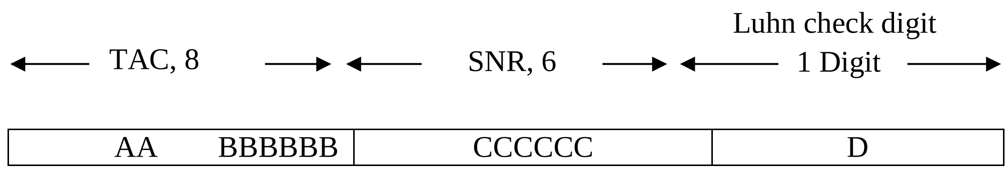


Figure 3.6: Structure and format of IMEI (Gianluigi and Alessandro, 2008).

In some cases, the Software Version number (SV) may also be embedded in the mobile equipment, and thus denoted as “IMEISV”. An IMEISV drops the Luhn check digit in favor of an additional two digits for the SV (GSMA, 2007), making the format *AA-BBBBBB-CCCCCC-EE*. Both IMEI and IMEISV include information on the origin, model, and serial number of the device (Rogier, 2006). The first two digits of the IMEI/SV, that is *AA*, represent the Reporting Body Identifier, allocated by the Global Decimal Administrator. Table 3.2 shows various Reporting Bodies and their respective identity codes.

Table 3.2: Reporting Body Identifiers (INP, 2010)

Reporting Body	**Reporting Body Identifier**
British Approval Board of Telecommunications (BABT)	35, 44, 97, 98, 99
Bundensnetzagantur (BNetzA)	48
BZT ETS Certification GmbH	49
National telecom Agency (NTA)	50
Telecommunication Terminal Testing & Approval Forum (TAF)	86
DECT PP with GSM functionality	10

An IMEI number can be assessed for compliance to the established standards. The Luhn check digit is a function of all other digits in the IMEI, the SV of mobile phone handset is not included in the calculation. The purpose of the check digit is to help guard against the possibility of incorrect entries to the EIR equipment. The presentation of the check digit, both electronically and in printed form on the label and packaging, is very important. For example, logistics (using bar-code reader) and EIR administration cannot use the check digit unless it is printed outside of the packaging, and on the Type Accreditation Label. The check digit is always transmitted to the network as "0" (GSMA, 2007; ITU, 1998).

The Luhn check digit is validated in three steps:

a) Starting from the right, double a digit every two digits (e.g., 7 → 14).
b) Sum the digits (e.g., 14 → 1 + 4).
c) Check if the sum is valid, it should be divisible by 10.

For the **example** IMEI 49015420323751ξ is checked as follows:

IMEI	4	9	0	1	5	4	2	0	3	2	3	7	5	1	ξ
Double every other	4	18	0	2	5	8	2	0	3	4	3	14	5	2	ξ
Sum digits	$4 + (1 + 8) + 0 + 2 + 5 + 8 + 2 + 0 + 3 + 4 + 3 + (1 + 4) + 5 + 2 + \xi = 52 + \xi$														

To make the sum divisible by 10, set $\xi = 8$; so, the IMEI is: 490154203237518.

3.5.3 Cell access technologies

Mobile phone networks use three common access technologies: Frequency-Division Multiple Access (FDMA); Time-Division Multiple Access (TDMA) and Code-Division Multiple Access (CDMA) (Schiller, 2003).

FDMA puts each call on a separate frequency. The spectrum is separated into distinct voice channels by splitting it into equal pieces of bandwidth and sending it out. This is used mainly for analog and not considered effective. This scheme is used for radio within the same region, where each radio station has its own frequency.

In TDMA, each cell is assigned a certain portion of time on a designated frequency. TDMA is a 30 MHz wide analog-channel broken down into 6.7 millisecond time slices with each split into three time slots. Voice data is compressed to digital information with less transmission space than analog. This access technology is used in the GSM phones and operates at 900 MHz, 1800 MHz and 2100 MHz in Kenya.

CDMA technology gives a unique code to each call and spreads it over the available frequencies by using spreading technology. Each phone transmits on all the allotted frequencies and uses a different random number to decide on a specific frequency. It assigns a code and time-stamp for each signal. It uses the global positioning system (GPS) to get information.

3.6 Electromagnetic radiation

3.6.1 Introduction

The term radiation refers to the energy traveling through space. There are two forms of radiation i.e. ionizing and non-ionizing radiation. Ionizing radiations have sufficient energy to ionize atoms that may destabilize molecules within cells and lead to tissue damage. Non-ionizing radiations are essential to life, but excessive exposures will cause tissue damage (Durney *et al.*, 1986).

The two types of *ionizing radiation* are particulate (alpha, beta and neutron radiation) and electromagnetic (x-rays, gamma rays) radiation. The higher frequencies of electromagnetic radiation (EMR), consisting of x-rays and gamma rays, are types of ionizing radiation. Lower frequency EMR, consisting of ultraviolet (UV), infrared (IR), microwave (MW), Radio Frequency (RF), and extremely low frequency (ELF) are types of *non-ionizing* radiation (OSHA, 2010). Figure 3.7 shows the spectrum electromagnetic radiation.

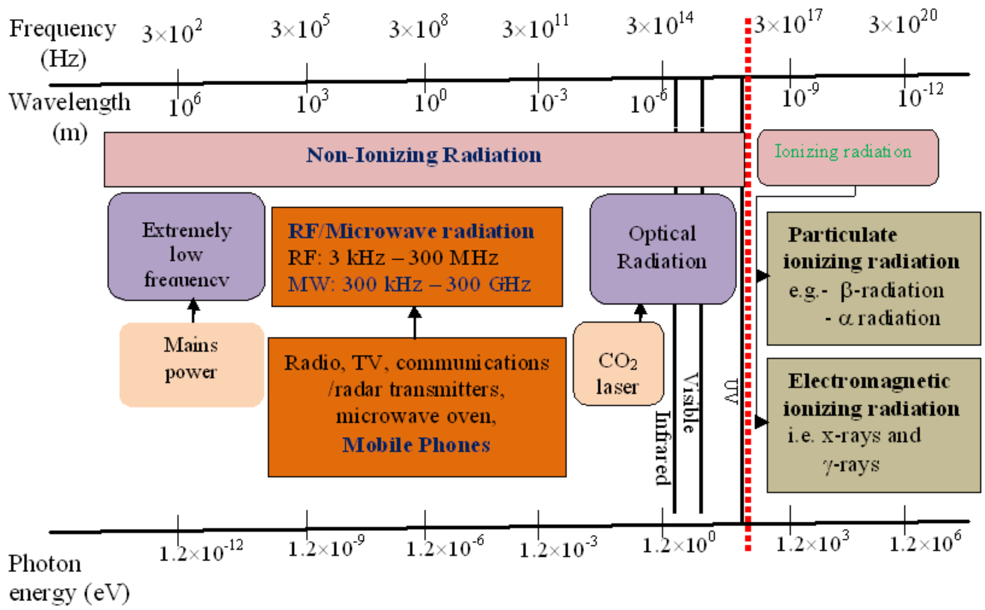


Figure 3.7: Electromagnetic spectrum (JOVE, 2001)

All EMR consists of waves of electric field $\vec{E}$ and magnetic fields $\vec{B}$ moving at right angles to each another and also to the direction of propagation of the energy. Thus, an electromagnetic wave is a transverse wave. The movement of electrical charges generates electromagnetic waves in the digital system or radiation through air and space (Hyland, 2000).

An electromagnetic wave is characterized by its wavelength λ and frequency υ. The latter determines the properties of EMR and the use made of it. EM waves of frequencies between 3 kHz and 300 GHz are widely used for telecommunication, including radios, microwaves, television, cellular phones, radar and communication transmitters comprise the radiofrequency (RF) band.

Microwaves and lasers, for instance, are forms of Non-ionizing radiation. Mobile phones operate in the microwave part of the spectrum. Since microwave radiation (including one from mobile phones) has a longer wavelength and consequently a lower frequency than x-rays and gamma rays, the energy they carry is considerably less. They therefore do not carry enough energy to break molecular bonds and create ions. GSM phones often use frequencies 900 MHz corresponding to 30 cm wavelength.

It is the microwave radiation, often referred to as radiofrequency (RF) signals that carry information such as speech and data between mobile phones via a base transceiver station (BTS) as shown in Figure 3.8. The RF signals, also called carrier waves, are pulse-modulated and send the desired information at the speed of light (3×10^8 ms^{-1}). The information can be transmitted in either analog or digital form, giving rise to analog and digital mobile phones. In analog transmission, the size or amplitude of the RF carrier wave at any instant is made proportional to the electrical modulating signal at that instant. Digital transmission of RF signal is discrete in nature, and is less susceptible to distortion by interference and electrical noise (Schiller, 2003).

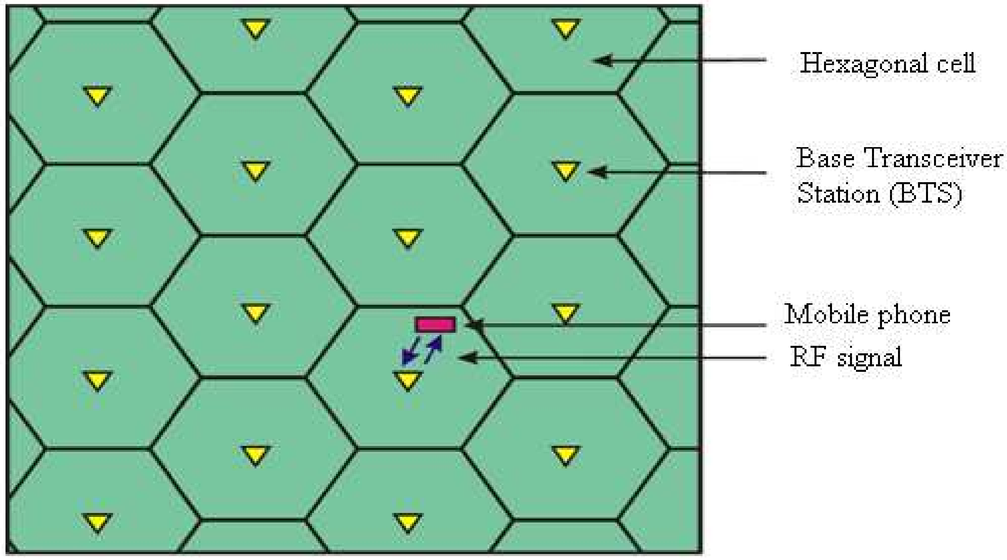


Figure 3.8: Radio signals travelling via the uplink from mobile phone to a base station and via a downlink in the reverse direction (IEGMP, 2000).

Radiofrequency signals are transmitted from the phone to the nearest BTS, and incoming signals are sent from the BTS to the phone at a slightly different frequency. The signals from the BTS are directional whereas those from the phone are non-directional. Thus radiation from a transmitting mobile phone antenna spreads around its horizons (Duff, 1976).

A mobile phone communication system divides an area of service into a set of cells, hexagonal shaped. A cell tower, or BTS in the center of the cell, covers an area of 5.12 or 7.68 km^2 around the tower. Mobile phones transmit to towers, which then connect the user to the normal land-based telephone system to route the call;

a handover has to happen when one moves from one cell to another. A typical large city has hundreds of towers and each carrier in each city runs a central office, known as the MSC. For example, as one moves from one city to another, the MSC hands-over mobile phone services to another cell (Marshall, 2002).

Whenever the phone is powered up, it listens for special frequencies (control channel) that the phone and BTS use to talk to one another. If there are no control channels, the phone is out of range and it thus displays a message 'no network coverage'. If the phone is within the network coverage range, it transmits a registration request so that the MSC keeps track of the subscriber's location in the database. The MSC then chooses a frequency pair that a subscriber uses in that cell (location) to take the call. The MSC communicates with the phone over the control channel to tell it what frequencies to use. Moreover, when the phone and the tower switch on those frequencies, the subscriber is then connected. As the phone user moves toward the edge of the cell, the BTS notes a diminishing signal and indicates that it is time for the control channel to handover to the next cell (Marshall, 2001).

The emitted microwave radiation is absorbed by tissues. This radiation is emitted not just during active usage, but also during standby mode, since the phone is continuously polling for location nearest to the base station (Duff, 1976). The Microwave energy absorption is measured in terms of Specific Absorption Rate (SAR) (GSMA, 2009).

3.6.2 Absorption of electromagnetic fields

Radiofrequency signals from a phone are transmitted by the antenna together with circuit elements inside the handset. The antenna is strongly non-directional and usually a metal helix or metal rod a few centimeters long (IEGMP, 2000). If the antenna is placed near the body, the radiation penetrates it but the fields inside the body are significantly less than the values outside. Besides the RF fields that are pulsed at 8.34 Hz and 217 Hz (Hyland, 2000), there are also magnetic fields near to the phone that oscillate at these frequencies and are a few μT in magnitude. These magnetic fields are generated by current flowing from the battery, when the phone is switched on and off at these frequencies because of TDMA (Usikalu and Akinyemi, 2007). The heating effect that all these fields produce would vary in intensity with the distance from antenna of a mobile phone.

Radiofrequency radiation inside the human body differs from the one measured outside the body. The rate at which RF energy is absorbed by a biological tissue is known as Specific Absorption Rate (SAR), given by the relation in Equation 3.9 (Damijan, 2006):

$$\mathrm{SAR} = \frac{\text{Energy absorbed}}{[\text{Exposed organ (or tissue)mass}]\times[\text{Irradiation time}]} = \frac{\sigma E^2}{\rho} \tag{3.9}$$

where:

σ = conductivity of biological tissue (Sm^{-1});

ρ = density of the tissue (kgm^{-3});

E = root mean square (rms) value of the electric field strength (Vm^{-1}).

The SAR is used in assessing the level of RF energy absorbed by the exposed tissues (IEEE, 1999). Various SAR reference levels have been set by various Organizations such as the U.S. Federal Communications Commission (FCC) and International Commission on Non-Ionizing Radiation Protection (ICNIRP). At present, the primary source of SAR data is from the phone manufacturers themselves. Some unwarranted exaggerations of the actual SAR value by the manufacturers have however been determined by STUK (2009). Such discrepancies have consequently led to a public outcry over the dosage of RF energy emitted from mobile phones (Krewski *et al.*, 2007).

Radiofrequency radiation is absorbed in terms of quanta of energy $h\upsilon$, where h is Planck's constant and υ is the frequency. These quanta of energy increase with the frequency of the signal. The intensity of this radiation determines the number of quanta striking the body per second. The fields also penetrate the body to an extent that decreases with frequency (Nit, 2007).

3.6.3 Suppression of electromagnetic fields

Attenuation of mobile phone radiation is an effective way of minimizing its exposure. In suppressing such radiation, anti-radiation filters are used to convert RF energy to thermal energy. This mechanism also involves the reflection of noise due to impedance mismatch at the boundary of the plate and free space, and multiple interference of noise inside the plate (Dano, 2000).

Anti-radiation filters are made of dielectric loss materials and resistive particles. Dielectric loss materials are composite materials that comprise of an insulator matrix such as plastic, ceramic, polyester and epoxy while resistive particles include carbon black and metals like copper, silver and nickel (Yoshihiro and Takahashi, 2008). They are made of different material-combinations and thus vary widely in effectiveness and performance. Examples of such materials are shown in Table 3.3 and 3.4.

Table 3.3: Electrical and thermal conductivities of various metal particles (Kenneth, 2010)

Metal	Electrical conductivity ($\times 10^{-6} cm^{-1}\Omega^{-1}$)	Thermal conductivity ($Wm^{-1}K^{-1}$)
Copper (Cu)	0.596	401.0
Silver (Ag)	0.630	429.0
Nickel (Ni)	0.143	90.9
Lead (Pb)	0.048	52.4
Carbon black (C)	0.001	30.0

Table 3.4: Dielectric constant of various materials (Clipper, 2010)

Material	Dielectric constant (k)
Ceramic	1.8-2.8
Polyester	2.6
Epoxy resin	3.6
Mica	2.6-3.2
Titanium oxide	40-50

3.6.4 Radiation exposure and evaluation standards

Exposure to RF radiation is categorized based upon the user's awareness and ability to exercise control over it. The two categories defined are occupational (controlled) and general-public (uncontrolled) exposure. Occupational exposure applies in the situation where persons exposed, because of their employment, have been made fully aware of the potential effects of the exposure. General-public exposure applies where the people may be unwary exposed or persons who are exposed as a consequence of their employment may not be made fully aware of the potential effects or cannot even exercise control over such exposures (WHO, 2006).

Radiofrequency radiation can be assessed in terms of the amount of radiation absorbed by the body i.e. specific absorption rate (SAR). In determining SAR, tissue equivalent "phantoms" are used instead of real bodies in experimental dosimetry. The amount of energy received at a location, such as the brain, from a mobile phone is usually measured as the energy received per second over a specific area (Stefani and Dean, 2009). CENELEC (2001) has shown that maximum power of mobile phone radiation should be about 2.5 - 3.0 W, since average adult brain is about 1.5 kg (Guyton, 1976). The SAR limit for public exposure is 1.6 Wkg^{-1} for the FCC and 2.0 Wkg^{-1} for the ICNIRP, averaged over 1.0 g and 10 g of tissue respectively (GSMA, 2009; Masao *et al.*, 2008; Honeywell, 2006; FCC, 1997).

The exposure limits are also determined in terms of power density, whose reference levels for two GSM frequencies are shown in Table 3.5. The limits for general public and occupational exposure are averaged results for six (6) minutes and thirty minutes (30) exposure (ICNIRP, 1998; Durney *et al.*, 1986)). The acceptable occupational limit(s) is generally higher than general-public because it is believed that the exposed person has been trained to recognize related health hazards and has some control over such exposure (Barnes, 1999).

Table 3.5: Radiofrequency radiation exposure limits for occupational and general-public (Barnes, 1999; CEC, 1991).

Safety standard	Power density levels at 900 MHz (mWm^{-2})		Power density levels at 1800 MHz (mWm^{-2})	
	Occupational	General-public	Occupational	General-public
ICNIRP	2.418	0.451	4.297	0.902
FCC	3.000	0.600	5.000	1.000
ANSI/IEEE,1992	3.000	0.600	6.000	1.200

3.7 Measurement of radiation intensity: Technical considerations

In measuring the intensity of RF radiation, the following technical considerations are included: temporal averaging, spatial averaging, frequency range and antenna directivity (Masao *et al.*, 2008).

3.7.1 Temporal averaging

Limits are usually expressed in *rms* values of continuous averaging over a defined period. For public exposure, ICNIRP reference limits are to be averaged over any six (6) minutes period and thirty (30) minutes period for occupational exposure, for frequencies less than 10 GHz. Therefore, for strongly time-dependent signals, an elaboration of measurement results (post-processing) may be necessary to be compared with the limit (Durney *et al.*,1986).

3.7.2 Spatial averaging

Averaging of initial measurements in a grid or near a radiator, yield the maximum point of field values. These values represent the most conservative evaluation of the exposure (Goiceanu and Dănulescu, 2006).

3.7.3 Frequency range

Measurement devices are classified into two: broadband and narrowband. Broadband devices, simultaneously respond to all the frequencies within a wide frequency range. These instruments can rapidly measure the total field level, but they can neither measure the frequency of the fields, nor separate the contributions of the fields with different frequencies to the total field level. Narrowband instruments are tuned before measuring and they scan the frequency range of interest with larger or smaller steps. They also measure the frequency of the fields and determine the contributions of all the frequencies to the total field level (Goiceanu and Dănulescu, 2006).

3.7.4 Antenna directivity

Antennas are either isotropic or directional. Isotropic antennas respond to incident EMF around it whereas directional antenna is dependent of the direction of incident radiation. Directional antenna is generally polarized and has an axial symmetry in the radiation pattern (Kitchen, 2001).

3.7.5 Calibration requirements

For broadband probes, the **calibration factor**, C_f, is defined in the following formula in Equation 3.10 (ICNIRP, 1998):

$$C_f = \frac{E_{ref}}{E_{meas}} \tag{3.10}$$

where,

E_{ref} = Reference electric field strength;

E_{meas} = Measured electric field strength.

The C_f is a function of frequency and field strength, determined in the absence of non-linearity errors. For each frequency, the C_f value is known with uncertainty of less than 1 dB. Errors due to frequency interpolations are included in the tolerable uncertainty on the C_f.

The **antenna factor**, A_e, is defined for antennas and frequency selective probes in the ratio given by Equation 3.11:

$$A_e = \frac{E}{V} \tag{3.11}$$

where,

E = Magnitude of electric field strength on the probes;

V = Voltage measured by the spectrum analyzer.

Antenna factor (A_e) is primarily a function of frequency but, in the presence of non-linearity errors, may depend on electric field strength. For each frequency, A_e value is known with an expanded uncertainty of less than 2 dB. The maximum tolerable uncertainty includes all error due to frequency interpolation.

CHAPTER FOUR

4.0 MATERIALS AND METHODS

4.1 Introduction

This chapter outlines the GSM mobile phone handset(s) under test (HUT), equipment, materials and measurement protocols used for data collection/acquisition and analysis.

Different models of mobile phone handsets were sampled based on their cost, model (type) and manufacturer/origin. These HUTs were fully charged to avoid the risk of switching off during the process of radiation measurement(s). The handsets under study were: Nokia-1100, 1110, 1200, 1202, 2626, 1661, 6300; Nokia *Series* N95; Smadl-A30, A56; Tecno-T570, T780; TV22i; iPhone- i9+; Long Ke- S350; TOP-1 006; J-Max- Double Life; Samsung- GT-E1080T; Blackberry-7290; Motorolla C118; Simba FV100, Zetel N85y and G-Tide (G19). The details of each handset were obtained from the information in the compliance plate mounted in battery compartment and respective IMEIs.

4.2 Radiation measurement set-up

The measurement system, shown in Figure 4.1, constitutes a broadband RF meter (NBM-550) connected to the PC via Universal Serial Bus (USB) and spectrum analyzer (FSH18) connected to PC through a RS-232-C optical interface.

The intensity of RF energy was measured by NBM-550 connected with $\vec{E}$ isotropic probe. In monitoring the signal strength and frequency specific to GSM band (900 MHz), FSH18 was connected with antenna module (HE300).

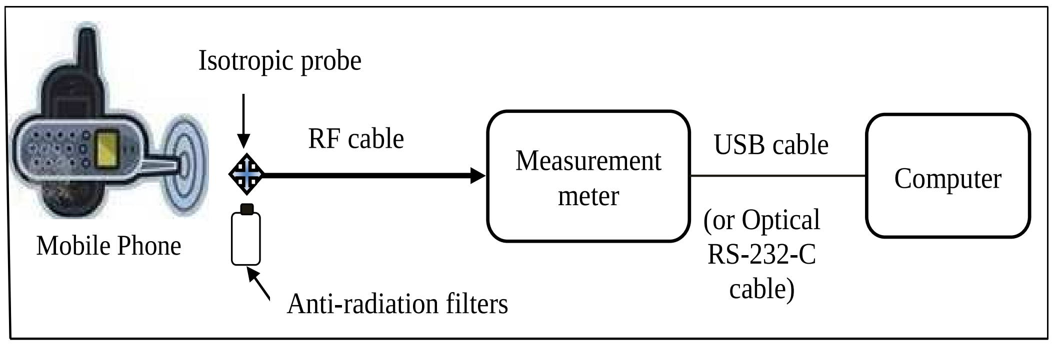


Figure 4.1: Experimental set-up for mobile phone RF radiation measurement

4.3 Materials and equipment

This section outlines the equipment and materials used in this study. The Materials used were mainly three anti-radiation filters from different manufacturers. The main characteristics and operation of the equipment used, i.e. broadband RF meter (NBM-550) and spectrum analyzer (FSH18), are discussed.

4.3.1 Broadband RF meter (Narda/German: NBM-550)

A broadband RF meter, shown in Figure 4.2, was used to measure the intensity of radiation ($mWcm^{-2}$) emitted from mobile phones under-study. Depending on the connected probe, this equipment measures radiation within the frequency range of 100 kHz and 60 GHz. The general specifications for NBM-550 are shown in Appendix A.

Figure 4.2: Measurement of data from Broadband RF meter – NBM-550

An *E*-field flat frequency response probe used to evaluate radiation levels according to a specific safety standard was set in NBM-550 monitor. This probe is calibrated separately from the measuring instrument, and has a non-volatile memory containing the probe parameters and calibration data. It measures electric fields in XYZ planes, performs vector addition of individual readings, and sends the results on the display provided by NBM-550 monitor. An infinitesimal electric dipole (or electric gap) detects the E-field by the components parallel to the dipole whereas an infinitesimal magnetic dipole (or small loop) responds to the dipole moment or perpendicular to the loop face. The frequency range of the electric field probe (EF-1891) is 3 MHz to 18 GHz and field strength of 600 mVm^{-1} to 1.0 kVm^{-1} (Appendix A).

The measurement data was transferred, as shown in Figure 4.2, to the PC from NBM-550 monitor by screen shooting the results or this could also be done using data Transfer Software NBM-TS. The latter also aids in data management and documentation of results for future evaluation.

4.3.2 Spectrum analyzer (FSH18)

The handheld spectrum analyzer (FSH18), from Rohde & Schwarz GmbH & Co. KG, is shown in Figure 4.3. This equipment (details shown in Appendix B) was used for monitoring of RF signals frequencies and it responds to a signal of frequency range of 10 MHz to 18 GHz. It can also measure field-strength, TDMA and channel power depending on the available accessories. Connected with a directional antenna

HE300, the spectrum analyzer determines the frequency and power flux density of E-fields. The frequency of HE300 antenna module ranges from 500 MHz to 7.5 GHz. Measurement data is transferred to the PC from the spectrum analyzer (Figure 4.3) using FSH View software.

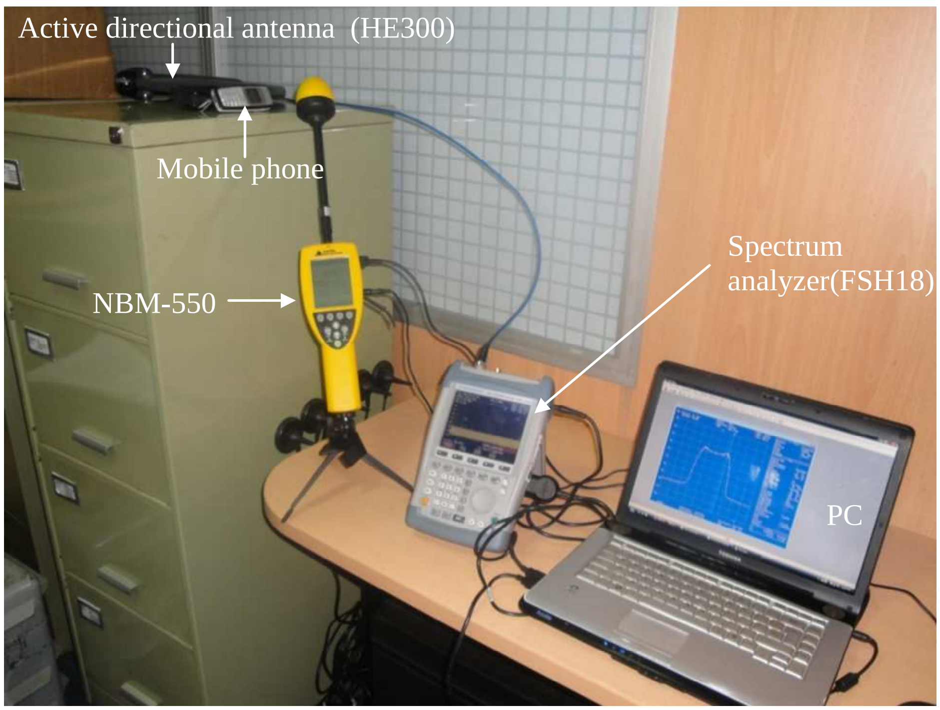


Figure 4.3: Overall radiation measurement system: NBM-550 and FSH18 interfaced to the computer for data collection

4.3.3 Anti-radiation filters

Anti-radiation filters were used to suppress the radiation from a transmitting mobile phone. These anti-radiation filters, sampled from three different manufacturers in order to compare and assess their efficiencies, include “Wave Scrambler”, “Safe Guard” and “EM wave Protection Sticker”. The filters used in this study are shown in Figure 4.4.

Figure 4.4: Anti-radiation filters (a) Wave Scrambler (b) Safe Guard (c) EM wave Protection Sticker

4.4 Protocols for the measurement of electromagnetic radiation

The RF signal from a transmitting phone was detected by *E*-field isotropic probe and antenna module, and then applied to broadband RF meter (NBM-550) and spectrum analyzer (FSH18) respectively. This was done in two stages: determination of background radiation (BGR) and radiation level(s) from handset under test (HUT).

4.4.1 Preparations for electromagnetic radiation measurement

In surveying the EMR, *E*-field probe (EF-1891) was connected to the broadband RF meter. The field meter was mounted on a non-conductive tripod stand (0.1 m) so as not to perturb electromagnetic fields. The subsequent procedures involved are as follows:

a) The battery charge of NBM-550 was checked by holding down the ON/OFF key. The remaining time could be shown as 25%, 50%, 75% or 100%. The battery voltage is also displayed during the self-test process wherever the instrument is switched on. After checking the battery status, the meter was switched on.

b) The probe (EF-1891) was connected to NBM-550 basic unit by ensuring that the red dot on the probe plug aligns with the red dot on the socket of the device. The locking sleeve is held and pushed straight down into the plug socket until the plug clicks into place. When disconnecting the probe from the instrument, the sleeve on the probe plug was slid upwards and then the probe pulled upwards to remove it.

c) The radiation meter was then switched on by pressing the ON/OFF key. The meter switches on and first performs a self-test, the alarm, LEDs (light up) and all the display elements are visible, hardware is checked and calibration factor 'CAL' (3 or 4) are alternately displayed, the battery voltage state is represented by four-stage bar graph display and the end of the self-test is indicated by a beep.

d) The analog display always shows the instantaneous measured value. The digital display shows the instantaneous value or stored result according to one of the following four modes: MAX, AVRG, Spatial AVRG and MAX AVRG. The average (AVRG) must be selected. The four modes are stored internally by the device and whenever a mode is changed, the calculations are done according to the selected mode.

e) The unit of measurements ($mWcm^{-2}$) was also set. This was done by pressing the OK key to open the 'menu and functions' and then selecting 'Measurement settings'.

f) The average time was set in the 'Averaging time' function by pressing the OK key and selecting 'Measurement settings/Averaging time menu'. The required averaging time is set by selecting the digit using the SHIFT keys and the pressing OK key to confirm the settings.

g) To start off measurements, the START key (soft key) was then pressed and countdown started. The measurement duration was referenced to six minutes (for general-public exposure) (ICNIRP, 1998). The measurements could then be stopped after six minutes and the data stored by pressing STORE key.

Background radiation levels were established in the Measurement Room for three consecutive days and monitored for consistency. These radiation levels were used as baseline for mobile phone radiation measurement.

4.4.2 Assessment of RF signal using spectrum analyzer FSH18

The procedure of assessing RF signal using spectrum analyzer FSH18 was as follows:

(i) The FSH18 was powered and the yellow button at the left button of the front panel pressed to switch it on. When the spectrum is switched on, it recalls the settings it was using when it was last switched off.

(ii) The FSHView V13.12 was installed in the computer (PC) to facilitate downloading of data from the spectrum analyzer. RS-232-C optical interface was subsequently connected from FSH18 to the PC.

(iii)The antenna module HE300 was connected to FSH18 as follows: the release switch on the handle of the antenna module was slid to the left and then the red dot on the module was aligned with the antenna socket before it was pushed in gently as shown in Figure 4.5a. The release switch was then slide back to the locked position as shown in Figure 4.5b.

(a) (b)

Figure 4.5: Release-switch of antenna module HE300 (a) locked, (b) unlocked

(iv) The frequency was set as follows:

The start and stop frequencies were set by pressing the FREQ key. On opening the softkey menu, the START and STOP keys were respectively pressed and the numeric values entered using the numeric keypads and then confirmed by pressing MHz key to set the units. Frequencies and other parameters that were used are shown in Table 4.1.

Table 4.1: Spectrum analyzer measurement settings for GSM mobile phones

GSM Frequency: 900 MHz	START(MHz) 876 921	STOP(MHz) 915 960	 (uplink) (downlink)
Carrier Spacing (or BW)	200 kHz		
Threshold	40 dB		(below reference level)
Access type	TDMA		
Sweep-time	700-1000 ms		

4.4.3 Measurement of power density of RF radiation

In order to activate the full functionality of the mobile phone under study, a SIM card was inserted into the test and control mobile phone handsets and then activated. The “incoming call” settings for the control phone *c* were then disabled to curb down any interference from any incoming call. Phone *c* was placed at far-fields and dedicated for triggering calls into the target handset. Thus, the contribution of radiation from the control phone was accounted within the BGR levels.

Measurement of RF power density (I_x) of the test handset was done at defined intervals of time under different exposure conditions. The latter consists of voice calling, use of anti-radiation filters and physical condition of the handset under test (HUT). In determining respective radiation levels, the handset was activated and positioned in a normal operating position with the center of its earpiece aligned with the location of the flat isotropic probe of the radiation meter was shown in Figure 4.1. The incoming call was instantly answered and then HUT oriented around the RF detector so that it would give the strongest signal. Once the strongest signal was found, HUT was kept on the table in the same position during the measurement process so as to minimize reading errors. The broadband RF meter measured the cumulative radiation intensity, denoted as I_c (contribution of mobile phone and background radiation). The process was repeated for each handset at least thrice to evaluate consistency of the results.

To assess the power density due to the use of anti-radiation filters (shown in Figure 4.6), the filters were respectively mounted and calls initiated onto HUT. In installing the “Wave Scrambler” (Figure 4.6(a)), it was first unpackaged, protective packing torn-off and pressed onto the earpiece as well as at the rear (directly behind the earpiece) of the handset. The battery was then removed from the mobile phone, battery compartment wiped clean using a clean dry piece of cotton and Wave Scrambler’s internal antenna was pressed onto the body of the handset (within the battery compartment). The battery was subsequently replaced and handset activated for radiation measurements was shown in Figure 4.1. The pad of “Safe Guard” filter (Figure 4.6(b)) was stuck on handset’s earpiece whereas “EM Protection Sticker” was installed onto the body (in battery compartment) of the handset under study. Figure 4.6 shows various positions where anti-radiation filters were mounted. Each of the three filters were separately installed onto a handset, say Tecno T570, and six averaged radiation measurements made for different handset models.

(a) (b) (c)

Figure 4.6: Mounted anti-radiation filters. (a) On the compliance plate; (b)/ (c) on the earpiece

To assess the effect of handset's physical condition against the intensity of radiation, Nokia 1202, Blackberry 7290, Smadl A30, Long Ke S350, TV22i and iPhone i9+ were used as study samples. The intensity of radiation from the handset(s) was measured with and without a battery cover and the results were compared with the respective normal radiation levels (around the earpiece).

4.4.4 Measurement considerations

Before starting the measurements, information about the characteristics of the mobile phone and exposure situations were taken into account for protection against exposure to high-level RF fields. In determining the characteristics of a mobile phone, its operating frequency, emitted power, polarization (orientation of $\vec{E}$ or $\vec{B}$) and modulation characteristics were assessed. Information about the exposure situation focused on the phone model, distance and existence of any scattering objects between the source and irradiated person.

The first measurement(s), therefore, was carried out at some distance away from the transmitting mobile station where it was estimated to have low risk on both the operator and the measuring instrument. EMR measurements were carried out in all points within the propagation radius where significant levels were estimated to occur.

4.5 Data collection

Data collection of the intensity of the mobile phones was carried out as follows:

(i) Measurement of background radiation (BGR) was carried out for three consecutive days and its consistency as well as variation trends evaluated to determine appropriate measuring period(s).

(ii) Measurement of the intensity of RF radiation around the ear-piece and rear/battery region of each activated HUT was respectively carried out under the normal operating condition (i.e. when no filter is mounted on a handset) and when anti-radiation filter(s) have been installed.

(iii) Data for each HUT was stored in the measurement devices and downloaded into the computer for further analysis. The data acquisition software that were installed include FSHView V13.12 and NBM550-Firmware_V1_2_0.

(iv) The IMEI(s) of each handset was obtained from the compliance plate of mobile equipment and that stored in its software. In obtaining the latter, the mobile stations were activated and the code: *#06#, was dialed. An IMEI(s) displayed on the LCD of the mobile phone were appropriately recorded down.

4.6 Data processing

i) Averaging of the measured radiation levels was done so as to determine radiation level for each of the handset under study.

ii) In determining the intensity of mobile phone radiation, the relation shown in Equation 4.1 was used:

$$I_x = I_c - I_b \tag{4.1}$$

where:

I_x = intensity of radiation emitted from HUT x;

I_c = cumulative power density;

I_b = intensity of background radiation.

The BGR levels are graphically plotted so as to assess its varying trends with time and also obtain the mean radiation level.

iii) The radiation levels for various handsets, under different exposure conditions, have been tabulated and plotted in form of Histograms for easy comparison and analysis. Graphical analyses were performed using SPSS 12 and Microsoft Office Excel 2007.

iv) The efficiency of anti-radiation filters is calculated as by Equation 4.2:

$$\eta_{f_i} = \frac{I_{x_{f_i}}}{I_{x_0}} \times 100, \tag{4.2}$$

where,

f_i = anti-radiation filter type *i*;

η_{f_i} = Efficieny of anti-radiation filter;

$I_{x_{f_i}}$ = intensity of mobile phone radiation with anti-radiation filter;

I_{x_0} = the intensity of mobile phone radiation without anti-radiation filter.

CHAPTER FIVE

5.0 RESULTS AND DISCUSSSIONS

5.1 Introduction

This Chapter begins by reporting results and assessing background radiation levels within the vicinity of the measurement room against ICNIRP and FCC standards; and also determining suitable period(s) for measuring radiation levels from the selected mobile phone handsets under test. The Chapter then reports and discusses the measured radiation levels from respective HUTs stated at standard uncertainty of $\pm\ 5.773\times10^{-5}$ $mWcm^{-2}$. This assessment focus on radiation results measured around the ear-piece and rear/battery cover region in the presence and absence of anti-radiation filters. The IMEI(s) of each handset's has also been assessed and subsequently co-related with the radiation level(s) thereof. Possible hazards emanating from radiation levels under different exposure conditions are also assessed.

5.2 Background radiation

In this study, measurement of background radiation (BGR) levels has been carried out to determine the baseline exposure of the general-public to electromagnetic radiation within the measurement vicinity of CCK's premises. It has further enabled the monitoring and isolation of the BGR levels (in the measurement room) from the mobile phone radiation level. This has provided an assessment mechanism based on the underlying BGR dynamics. Figure 5.1 shows a graphical representation of average BGR levels with time of the day.

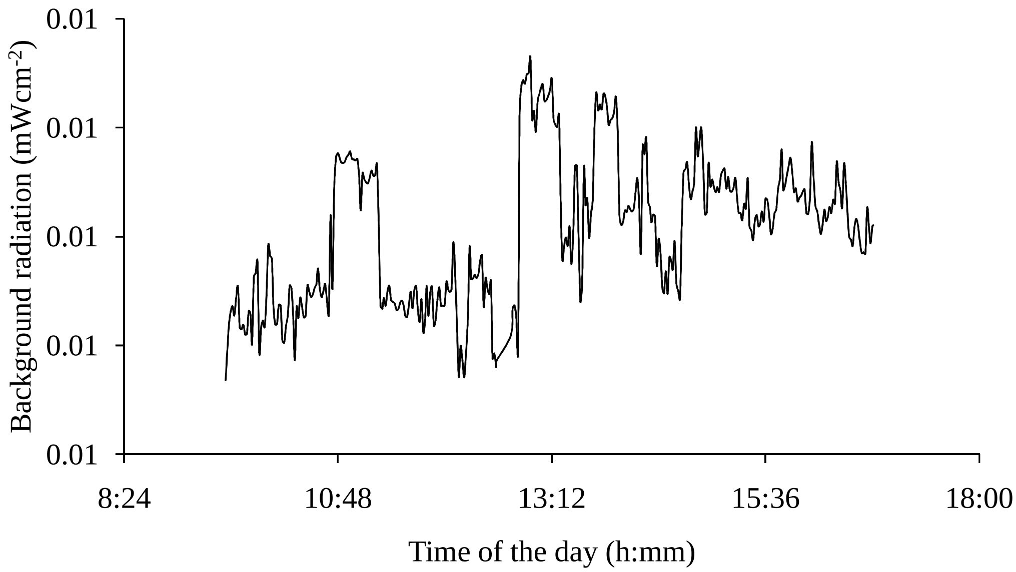


Figure 5.1: Variation of average background radiation with time of the day

The results in Figure 5.1 have shown that the power density of the background radiation ranged from 0.0077 (1.7% of ICNIRP Reference level) to 0.0106 $mWcm^{-2}$ (2.4% of ICNIRP Reference level). Minimum and maximum peak intensities are observed at 9.32 am and 12.57 pm respectively. The average BGR value is 0.0090 $mWcm^{-2}$ (2.0% of ICNIRP Reference level), with 4.3735×10^{-7} variance index.

In Figure 5.1, it is also clear that the BGR in the morning and afternoon greatly contrasts. Average BGR before noon is 0.0086 $mWcm^{-2}$ (1.9% of ICNIRP Reference level) whereas in the afternoon, it is 0.0093 $mWcm^{-2}$ (2.1% of ICNIRP Reference level). The low BGR levels witnessed in the morning hours are as a result of little mobile-communications owing to a hub of office activities and may also be attributed to low solar activity. Notable increment of BGR is also however observed between 10.30 am to 11.15 am; this can be attributed to radiation from mobile phones that accrue from increased GSM traffic volume due communications by people within and around the CCK premises (during the tea break session). Maximum radiation levels were observed at lunch break, between 12.56 pm and 2.15 pm. During this period, the traffic in the GSM network is usually high; hence the increase in the background radiation in the measurement vicinity.

The variation of BGR, shown in Figure 5.1, is possibly due to the uncontrolled nature of the transmitting sources. Such sources include radiation from nearby base stations, broadcast radio and TV transmitters, control machines in the CCK's Equipment Room, mobile phones within the measurement vicinity, optical sources (natural light and bulbs) and low power transmitting devices such as wireless burglar alarms, closed circuit TV, theft protection devices and computers.

5.3 Intensity of radiation from mobile phones

The intensity of radiation from various mobile stations, when establishing a call and during conversation was assessed as shown in Figure 5.2.

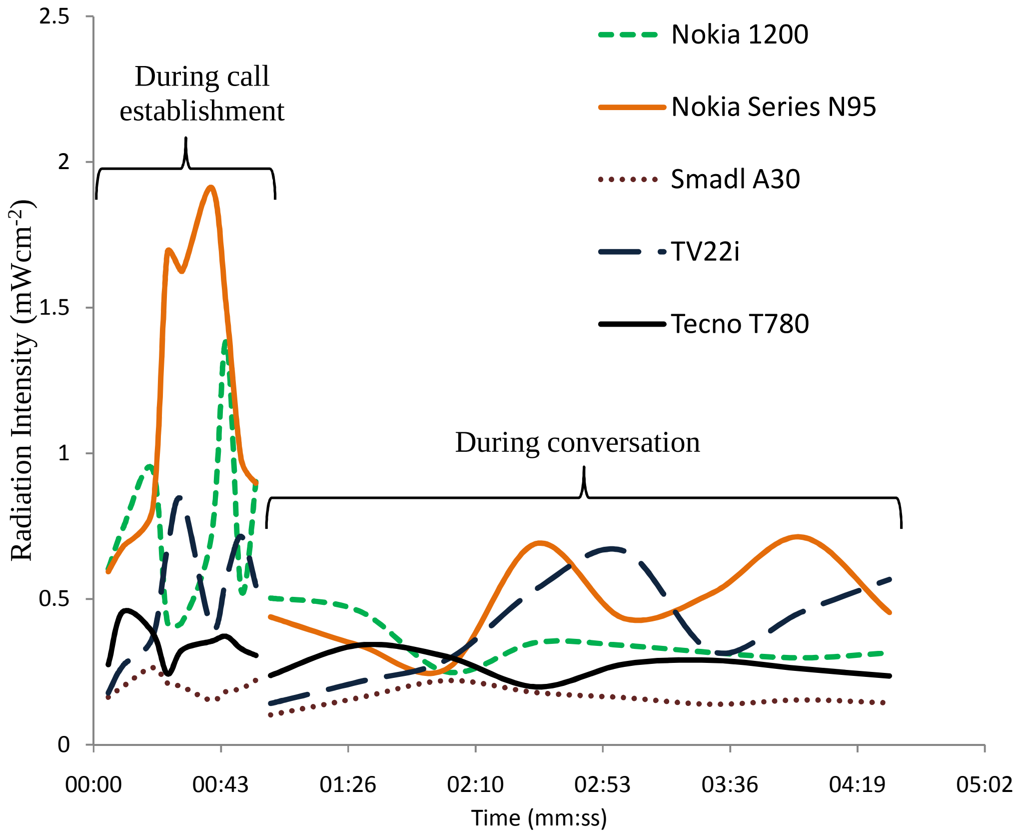


Figure 5.2: Variation of radiation intensity with time- during call establishment and conversation

The high power(s) witnessed when dialing the GSM network is needed by the mobile station in reaching and picking a signal from the base transceiver station (BTS). The apparent drop in power during conversation is attributed to adaptive power control (APC) and discontinuous transmission (DTX). An APC minimizes transmitter power of the handset and reduces multiple-access interference effect in order for the BTS to receive the usable signal. The DTX turns off transmission during pauses within speech, thus the user is exposed to the radiation arising from the conversation a part of the time only. The said phenomenon is witnessed whenever a transmitting handset is placed next to a speaker; the cracking noise (adverse electromagnetic interference effects) in the speaker degenerates with time after connection acknowledgement.

From the obtained results (Figure 5.2), it is apparent that mobile phone users who take long before “answering” a call are likely to be exposed to higher radiation levels. The accruing health effects may include heating and tingling of the exposed tissues especially the ear and thighs, headache and psychological disorders as reported by Barnes (1999) and Krewski *et al.* (2007).

Reduction of RF exposure applies the inverse square law (Durney *et al.*, 1986). Some measures to reduce RF exposure during call establishment include:

(i) The use of speakerphone, earpiece or headset:

This reduces proximity to the head (and thus exposure). Earpieces remove the greatest source of RF energy (the mobile phone) from proximity to the head and thus can greatly reduce total exposure to the head (FCC, 2010).

(ii) Increasing the distance between a transmitting mobile phone and body (NCRP, 1986).

(iii) Texting (i.e. use of SMS) rather than talking (Damir *et al.*, 2004).

A comparative study of average intensities among different activated mobile phones, during conversation, is presented in Figure 5.3. The mean intensity from each of the handset under study had the BGR subtracted and was shown to vary with handset model. The highest and least radiating handset was, respectively, Nokia Series N95 (0.4669 $mWcm^{-2}$, 104% of ICNIRP Reference level) and Nokia 1110 (0.0113 $mWcm^{-2}$, 25% of ICNIRP Reference level). The intensities of all the tested handsets, except N95, were below ICNIRP's recommended limit; however, the limit of N95 is within FCC reference level (0.600 $mWcm^{-2}$).

In this work, the intensity of radiation from N1100 was 0.1537 $mWcm^{-2}$, which is comparably smaller than the 0.451 $mWcm^{-2}$ reported by Usikalu and Akinyemi (2007). Such variation would be a consequence of change of the manufacturing technologies and different RF detection capabilities of measuring equipment used in these studies.

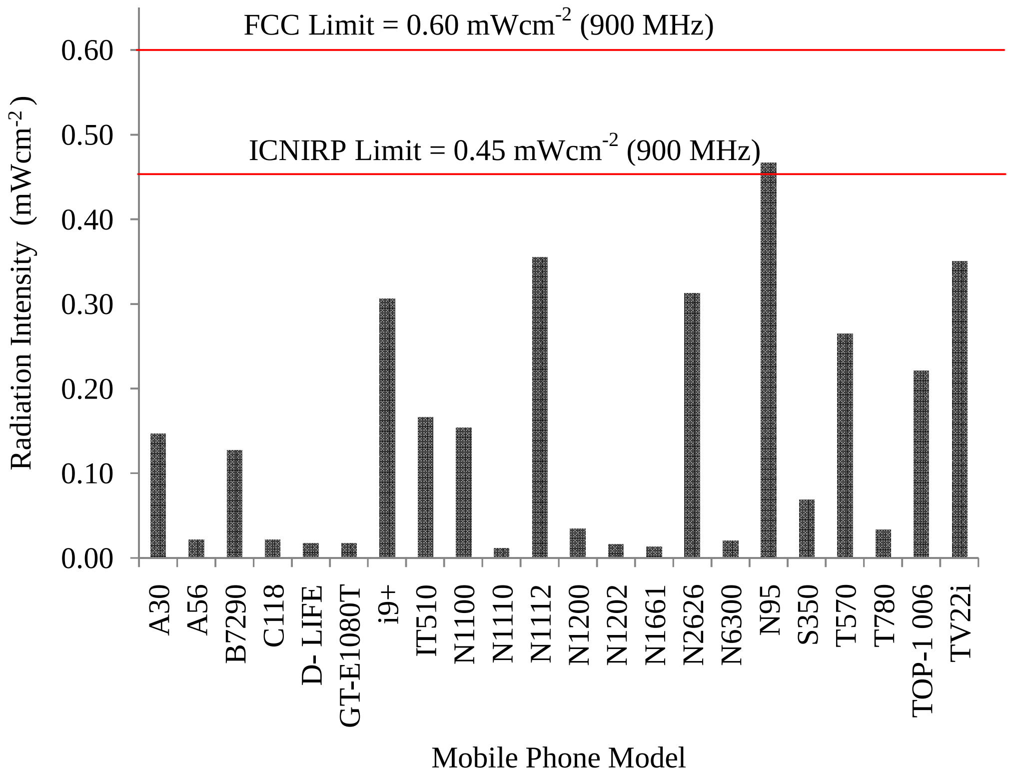


Figure 5.3: Intensity of radiation measured at the ear-piece among different handset models during the conversation mode

In determining the power density of sampled handsets, the base signal strength was constantly monitored. The signal strength within the measurement room was always determined to be stable. However if the measurement is carried out in poor network environment, Independent Expert Group on Mobile Phones (IEGMP, 2000) has shown that the power density of the HUTs would increase since the mobile phone will have to use a lot of power in order to hook up with the base transceiver station.

In this regard therefore, the use of N95 under such conditions would possibly be unsafe.

According to a study carried out by Damir *et al.* (2004), some of the properties such as Bluetooth services have been shown to increase the RF emissions. Usikalu and Akinyemi (2007) have further shown that if the calls were made while charging the batteries of mobile phones, extremely low frequency radiation (majorly from LCD display unit) would as well enhance the measured radiation. In the current study, similar observations have also been made.

5.4 Effectiveness of anti-radiation filters

The radiation levels resulting from the attenuation of electromagnetic radiation using anti-radiation filters among different selected mobile phone handset models is presented in Figure 5.4. It is observed that the use of anti-radiation filters lead to a significant red uction of the mobile phone radiation levels. The radiation reduction efficiency is also shown to vary with the type of anti-radiation filter.

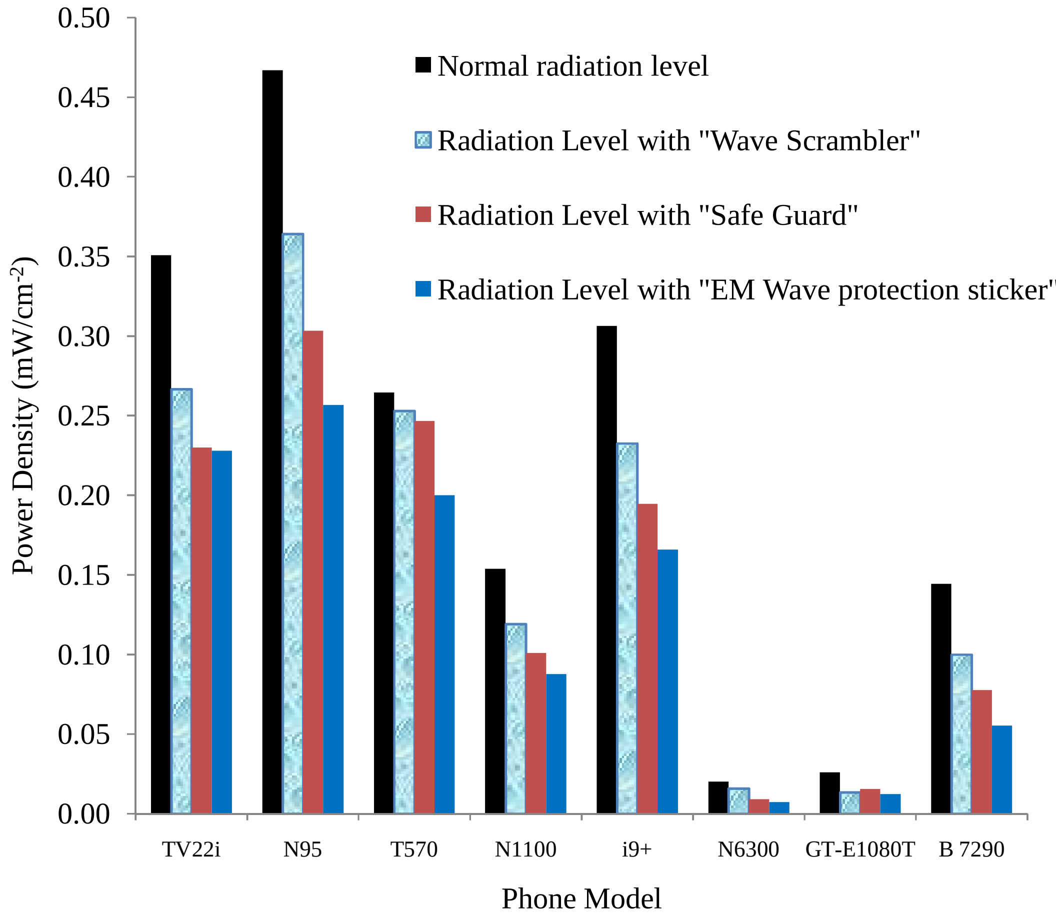


Figure 5.4: Radiation levels from different handset models with anti-radiation filters.

The incident electromagnetic radiation is suppressed at different rates with respect to anti-radiation filter-type per handset model, as shown in Table 5.1.

Table 5.1: Calculated (%) EMR reduction efficiencies of each filter-type per handset model

Handset model	Normal radiation level (I_N) ($mWcm^{-2}$)	Radiation Intensity ($mWcm^{-2}$) with anti-radiation filters		
		Wave Scrambler	Safe Guard	EM Wave Protection Sticker
TV22i	0.3508	0.2749 (-22.9%)	0.2301 (-34.4%)	0.2280 (-35.0%)
N95	0.4669	0.3642 (-22.0%)	0.3072 (-34.2%)	0.2661 (-43.0%)
T570	0.2647	0.2316 (-22.5%)	0.1721 (-35.0%)	0.1456 (-45.0%)
N1100	0.1537	0.1191(-24.1%)	0.0976 (-36.5%)	0.0832 (-45.9%)
I9+	0.3064	0.2310 (-24.6%)	0.2004 (-34.6%)	0.1547 (-49.5%)
N6300	0.0203	0.0157 (-22.5%)	0.0133 (-34.3%)	0.0113 (-44.3%)
E1080T	0.0261	0.0158 (-39.6%)	0.0167 (-35.9%)	0.0124 (-52.5%)
B 7290	0.1443	0.1117 (-22.6%)	0.0944 (-34.6%)	0.0799 (-44.6%)
Average	0.2167	0.1668 (-23.0%)	0.1414 (-34.8%)	0.1240 (-44.4%)

The obtained results have shown that of the three filters used, “EM Wave Protection Sticker” from LG was the most effective with an average efficiency of 44.8% whereas “Wave Scrambler” was 23.0% and “Safe Guard” was 34.8% effective. Although all the manufacturers of such products guarantee consumers 99% radiation reduction efficiency, it is evidently clear that none of them met this claim (SkyAuction, 2010; TV, 2010).

Amongst the mobile phones under study, the response of Samsung GT-E1080T to anti-radiation filters was highly favorable. The surface area of Samsung GT-E1080T’s ear-piece (where the filters were installed) was comparably small, thus leading to more effective suppression of the emissions around the phone.

The effectiveness of “Wave Scrambler” on Samsung GT-E1080T was also found to be 39.6% (more than the corresponding efficiency of “Safe Guard”, 35.9%, whose mean value was 34.8%).

The efficiency of “EM Wave Protection Sticker” in TV22i was 32.0% (far less than the mean value of 44.8%). Radiation from this phone was emitted from the antenna; however, minimal radiation levels were observed at the base of the antenna where the filter was installed. Due to size and filter specification, the protection sticker would not be mounted on the earpiece; otherwise, it would instead totally block the earpiece and affect communication.

The observed deviation of efficiencies of each filter type amongst various mobile phone models from respective mean values would be a result of varying background radiation and measurement errors. The quality of these filters, which as well depend on the storage conditions as well as duration of storage, may have also affected the outcome. One of the environmental conditions that affect filter’s performance is humidity. The rust that accrues out of these condition triggers rusting as well as the capability of the filters’ mounting adhesives.

Based upon the obtained results, the variation of mean efficiencies can also be attributed to the quality and material composition of the anti-radiation filter. The “Wave Scrambler” is made of special ceramics ($k = 1.8 - 2.8$) and copper. The vast majority of all structural and electrical ceramics conduct heat very poorly.

“Safe Guard” is made of fine strands of polyester ($k = 2.6$) coated with copper, nickel and carbon. Whereas polyester confines most of EMFs within the resonators, the crystalline entities that are coated onto it enhance conduction of heat. “EM Wave Protection Sticker” is made of epoxy resin ($k = 3.6$) and lead.

The type, amount and size of RF absorber materials also to a greater extent determined the effectiveness of such devices in blocking mobile-phone radiation (Kitchen, 2001; *Durney et al., 1986*). Of the three filters, the surface area of “EM Wave Protection Sticker” was the largest. This implies that the electromagnetic waves were exposed over a large area; thus neutralization and EMR shielding effectiveness of “EM Wave Protection Sticker” was comparably high, followed by “Safe Guard”.

Although Yoshihiro and Takahashi (2008) showed that the use of anti-radiation filters would compromise with speech quality performance owing to a corresponding reduction in power and quality of the connectivity signal, this study has affirmed their effectiveness in reducing the human exposure to such radiation.

5.5 Effect of handset's battery/rear-body cover on RF emissions

Unlike RF radiation from base stations, radiation from mobile phones is non-directional; that is it spreads over and around the user. Any opening, such as earpiece and battery cover, serves as exiting points for the radiation. In this study, the effect of handset's physical condition on radiation exposure levels has been examined by considering the state or nature of casing and its naked-state. Respective mobile phone radiation levels around the earpiece region, normal radiation level (I_N), are compared with radiation levels around the battery compartment area: with and without the battery cover. Radiation levels around the battery compartment region of the selected and activated mobile phone models, with and without a battery cover, was measured and assessed according to NIR standards. The results, presented in Figure 5.5, shows that the intensity of radiation around a transmitting (battery) uncovered handset was comparably higher than a transmitting battery-covered handset. It is also evident that neither of the said cases would emit radiation above its corresponding normal level (I_N).

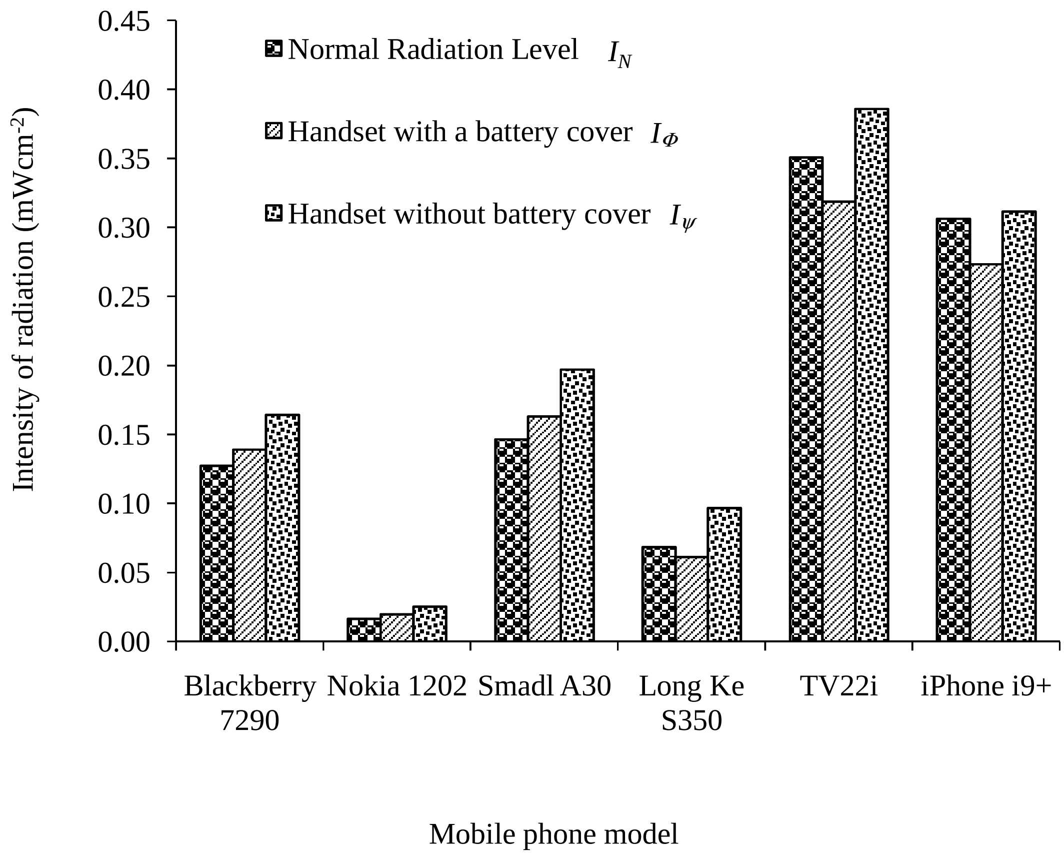


Figure 5.5: Radiation levels from selected handset models with and without battery cover

5.5.1 Radiation levels around mobile phone's battery compartment: With battery-cover

The results have shown that the intensity of radiation around a battery-covered compartment (I_Θ) with respect to normal radiation levels varied amongst the tested handsets. Whereas the I_Θ values of B7290, N1202 and A30 were above the respective normal radiation levels (I_N), the I_Θ of S350, TV22i and i9+ were below I_N.

The battery covers of S350, TV22i and i9+ are metallic but the casing of Blackberry 7290, Nokia 1202 and Smadl A30 are plastic in nature. From the obtained results, it is evident that metallic casing attenuated more radiation than plastic materials. Metals are generally very strong and hard (resistant to surface transformation or abrasion), and may have thus internally deflected and attenuated the emitted RF radiation. Although plastics are lighter than metals and do not rot or rust, they are of lower tensile strength; hence their attenuating capability is lower than that of metals.

Therefore the battery cover, or merely (for some handsets such as N1202) rear body-cover, serves as an attenuating medium. In its absence, the air (whose attenuating capability tends zero) acts as an attenuator.

5.5.2 Radiation Levels around mobile phone's Battery compartment: without battery-cover

The results shown in Figure 5.5 clearly demonstrate that radiation levels around mobile phone battery compartment, without battery-cover or rear body-cover, (otherwise abbreviated as I_{Ψ}) was above their corresponding and respective radiation levels (I_N) as well as I_{Θ}.

The evident rise in power density amongst all the tested mobile phones is mainly attributed to the apparent removal of the battery cover(s), which primarily served as an attenuator. The frequency response of probe is 3 MHz – 18 GHz; implying that low frequency radiation (LFR) from the battery was not measured. The existence of LFR (30 – 300 kHz) from the battery, according to Usikalu and Akinyemi (2007), would however be expected to contribute to the overall radiation level. According to their findings, such LFR would even increase when the phone is on charge.

This study has demonstrated that the use of an activated mobile phone with uncovered battery compartment would increase the user's exposure to RF radiation. Though none of tested phones emitted above recommended limits, the battery-covered handsets are much safer to use. It thus means that although a mobile phone can operate normally even in the absence of the battery-cover or even the rear body-cover, its effect on the emitted radiation cannot be ruled out. The loss of either part of the mobile phone, irrespective of its working condition, should therefore be replaced.

5.6 Assessment of mobile phones compliance to IMEI standards

The international mobile equipment identifiers (IMEIs) of the tested mobile phones were checked based on two methods: reading the IMEI on the compliance plate (white paper in the battery compartment) and IMEI displayed by the handset's software (by dialing *#06#). Both methods ought to give the same IMEI per mobile phone under study. Each IMEI was then analyzed on two accounts: Luhn Check-digit computation and International Number Plans (INP) scheme. The full spectrum of the IMEI results is presented in Table 5.2.

The mobile phones whose IMEIs displayed on the screen coincided with the code read on the compliance plate include: Nokia 2626, 1100, 1661 and 6300, Tecno T780, Samsung- GT-E1080T, J-Max Double-life and Blackberry 7290. Of all these IMEIs, only Blackberry 7290, Tecno T780, Nokia 2626 and 1661 perfectly matched with type allocation holder (manufacturer) as well as mobile equipment type in the INP database. The type allocation holder and equipment type of Nokia 1100, Nokia 6300, Smadl A56 and Samsung GT-E1080T was not available in the INP database. In spite of the coincidence of IMEI on the screen and that on the compliance plate of Smadl A30 and J-Max Double-life, these IMEI numbers were accredited to different mobile phone manufacturers (Hitachi and Siemens) and mobile phone models (Hitachi HTG-989 and Siemens S40 respectively).

Table 5.2: Analysis of IMEI numbers for the phones under study

Mobile equipment (ME)	IMEI		Origin	IME evaluation (INP)	
	Code displayed on screen (*#06*)	**Code read on the compliance plate**		**Type allocation holder**	**Mobile Equipment Type**
Nokia 2626	353942017756715	353942017756715	Hungary	NOKIA	NOKIA 2626
Blackberry 7290	357779000735454	357779000735454	Canada	Blackberry	Blackberry 7290
Tecno T780	354609020997706	354609020997706	China	TECNO	TECNO T780
Nokia 1661	355205031721638	355205031721638	India	NOKIA	NOKIA 1661/1662
Nokia 1100	357264013079151	357264013079151	Hungary	-	-
Nokia 6300	352943015160042	352943015160042	Hungary	-	-
Samsung GT-E1080T	357064038877945	357064038877945	Philippines	-	-
Smadl A56	354726030217642	354726030217642	China	-	-
J-Max Double Life	350077215552989	350077215552989	China	Siemens	Siemens S40
Smadl A30	353304000128305	353304000128305	China	Hitachi	Hitachi HTG-989
Nokia 1200	**350622020218092**	353265016021331	Hungary	**Kejian**; Nokia	**Kejian K7100**; Nokia 1600
iTEL IT510	135790246811220	353261030056783	China	-	-
Long Ke S350	354756500713920	354756500713919	China	-	-
Nokia 1202	357622024778177	355005360081046	Hungary	-	-

... Table 5.2: Analysis of IMEI numbers for the phones under study

Mobile equipment (ME)	**IMEI**		**Origin**	**IME evaluation (INP)**	
	Code displayed on screen (*#06*)	**Code read on the compliance plate**		**Type allocation holder**	**Code displayed on screen (*#06*)**
Tecno T570	357170023202005	357170023202005	China	-	-
	000000000000000			-	Test phone
Simba FV100	356688000028730	356688000028730	China	Amoi	Amoi M350
	000000000000000			-	Test phone
Nokia Series N95	357087084598438	357087084598438	China	-	-
	357087084598446			-	-
	357087083837787			-	-
iPhone i9+	354236021053491	355200903192324	China	-	-
	356893066053491			-	-
TOP-1 006	357357030179017	357357030179017	China	-	-
	357357030279015			-	-
Zetel N85y	352154000546902	352154000546902	China	TCL Mobile	TCL GA16 / TCL E757
	352154001546901			TCL Mobile	TCL GA16 / TCL E757
G-Tide (G19)	359005034010385	359005034010385	China	G-Tide	G-Tide M8 / G19 / G28
	359005034029880			G-Tide	G-Tide M8 / G19 / G28

The phones that displayed only one IMEI on the screen but a different code on the compliance plate include Nokia 1200 and 1202, iTel IT510 and Long Ke S350. The IMEI on the screen and compliance plate of Nokia 1200 indicated different type-allocation holders; with the later being, Nokia 1600 while the former as Kejian K7100. This implies that none of the IMEIs on Nokia 1200 would clearly identify this mobile equipment (ME). The IMEI displayed on the screen of IT510 was invalid; it would not be identified with any Reporting Body Identifier nor does it comply with Luhn Check-digit computation and specific information regarding this ME was missing in INP database.

Mobile phones with more than one IMEI codes displayed on the screen include G-Tide G19, Zetel N85y, TOP1-006, iPhone i9+, Nokia Series N95, Simba FV100 and Tecno T570. One of these IMEIs coincided with the IMEI number on the compliance plate of the corresponding and respective mobile phone. One of the IMEIs of FV100 and T570 was 000000000000000, an IMEI that is allocated only to test mobile phones. The other IMEI of FV100 was 356688000028730; a code accredited to a different manufacturer (Amoi) and model (Amoi M350). The specific information of G19 and N85y was readily obtained from their respective IMEIs. The details of i9+ and N95 were not accessible in INP database. The IMEI anomalies possibly implies that they have not passed through a standardized test and thus would be counterfeit products. From this study, however, it was established that there is no direct relationship between handset’s IMEI(s) and the emissions.

CHAPTER SIX

6.0 CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

Electromagnetic radiation levels varied with mobile phone models. The radiation levels from all the 22 tested handsets ranged from 0.0113 to 0.4669 $mWcm^{-2}$ with the highest radiating mobile phone being Nokia Series N95 while the least was Nokia 1110. All the mobile phone radiation levels, except N95, were within ICNIRP's safe exposure limits. Therefore, the use of N95 in the Kenyan market would be detrimental to the health of general-public. The radiation intensities from transmitting handsets, when dialing the network, were determined to be high and this would decrease during conversation.

The use of anti-radiation filters in suppressing mobile phone radiation has been found to be effective. Amongst the three anti-radiation filters used, "EM Wave Protection Sticker" from LG was the most effective (44.4%). Efficiencies of "Sage guard" and "Wave Scrambler" were 34.8% and 23.2%, respectively. None of these filters was 99% effective as asserted by the respective manufacturers.

The radiation levels from the mobile phones under-study were established to be affected by the nature and presence/absence of battery/rear-body cover. Radiation intensity around the battery compartment of all the transmitting handsets without a battery-cover (rear body-cover) was determined to be higher than the radiation levels from cased handsets and normal radiation levels (at the earpiece). Mobile phones with metallic casing such as TV22i, iPhone i9+ and Long Ke S350 attenuated much radiation than plastic cased handsets: Smadl A30, Nokia 1202 and Blackberry 7290.

All the tested mobile phones, except Nokia 2626 and 1661, Tecno T780 and Blackberry 7290, were not compliant to the established IMEI standards. The handsets with IMEIs belonging or allocated to different brands in the INP database include J-Max Double-life, Nokia 1200, Simba FV100, Smadl A30 and Zetel N85y. And 80% of the tested handsets contravened IMEI regulations- a clear indication that these mobile phones have not possibly passed through standard tests and approval procedures. In general, however, all the IMEIs were found not affect the level of RF emissions.

6.2 Recommendations

6.2.1 Future work

In this study, the radiation levels of 22 handsets were investigated based on established NIR standards. However, hundreds of different mobile phone models exist in the Kenyan telecommunication market and new entrants would be expected. Further studies should be directed to assess the radiation levels from such devices.

This study has examined the effectiveness of only three anti-radiation filters. Further studies should also be done on other filter types.

This work has explored the effect of only one physical parameter (battery cover or rear body-cover) of the mobile phone against the emitted radiation. More work should be done to assess how age of handset influences its physical state and the radiation thereof. Handset aging can be either electronic or physical aging.

6.2.2 Industry regulation

a) Some counterfeit mobile phones which are otherwise branded with genuine trademarks, such as Nokia and Samsung, at the expense of less-informed gullible customers would have found their way into the country. With a liberalized economy, stringent measures should be established so as to check, ascertain and regulate the standards of the mobile phones that are being imported and used in the country. It would be safer if the mobile phones used in the country were imported directly from manufacturers, who can guarantee their certification and safety.

b) To protect the general public from RF exposure, the Communication regulator should one NIR standard. INCIRP standard is of superior advantage over FCC due to its low reference exposure level (see Table 3.5) which give effective restrictions on exposure to EMFs and associated health effects. Therefore, only the use of ICNIRP compliant mobile phones should be allowed in the country.

c) The communications industry regulator in liaison with Kenya Bureau of Standards (KeBS) should establish modern RF Laboratories to check the standards of mobile phones imported into the country and measure to establish the radiation levels from these devices before they are put to use.

d) Concerning the IMEI incompliant mobile phones, the industry regulator should direct mobile service operators to disconnect such devices from the communication network.

REFERENCES

Abdel G. R. (2006). Neurobehavioral effects among inhabitants around mobile phone base stations. *Neuro Toxocology*, **21**(4): 19-23.

Agar J. (2003). *Constant Touch: A Global History of the Mobile Phone*. Cambridge: Icon Books.

Anita G. G. (2005). Genetic damage in mobile phone users: some preliminary findings. *Indian Journal of Medical Genetics* , **11**(2): 99-103.

Arunga J. and Kahora B. (2007). *The Cell Phone Evolution in Kenya.* International Policy Network and Istituto Leoni.

Atique A. K. (2005). *Security & Vulnerability Analysis of Wireless Messaging Protocols & Applications.* Retrieved June 11th, 2010, from http://www.securitydocs.com/library/3026

ATMR (Africa Telecom Market Report). (2009). *Africa Telecom Market Report:2008-2009.* Research and Markets Ltd. pp. 12-13

AWC. 2010. Kadium Publishing (Pty) Ltd. pp.41

Balanis, C. A. (2005). *Antenna Theory Analysis and Design.* Newyork: John Wiley & Sons, Inc.

Baranski S. and Czerski P. (1976). *Biological effects of microwaves.* Stroudsberg, Stony Brook, USA.

Barnes H. J. (1999). Cell Phones: Are they Safe? *American Society of Safety Engineers*, **3**: 20-22.

BASCAP. (2009). *Consumer Attitudes and Perceptions on Counterfeiting and Piracy.* Business Action to Stop Counterfeiting and Piracy.

Baumann J., Landstorfer F., Geisbusch L. and George R. (2006). Evaluation of radiation exposure by UMTS. *Electronic Letters*, **42**: 225-256.

CCK. (2008a). *Communication Statistics Report 2008*. Retrieved June 10, 2010, from www.cck.go.ke/resc/statistics/communication_statistics_report_2008.pdf

CCK.(2008b). Wireless phone technologies. Communications Commission of Kenya. Nairobi, Kenya.

CCK. (2010a). *Quaterly Sector Statistics Report:* 2nd Quarter, Oct-Dec 2009/2010. Communications Commission of Kenya, Nairobi. pp.4

CCK. (2010b). *It is now Mandatory to register your SIM Card.* Retrieved July 10, 2010, from Communications Commission of Kenya:

http://www.cck.go.ke/news/2010/news_21june2010.html

CEC. (1991). Safety levels with respect to human exposure to radiofrequency electromagnetic fields, 3kHz to 300GHz. *Health Physics,* **71**(3): 500-512.

CENELEC. (2001). Basic standard for the measurement of specific absorption rate related to human exposure to electromagnetic fields from mobile phones (300 MHz - 3 GHz). *Official Journal of the European Communities,* **84**(5): 440-456.

CEPT. (2003). Measuring non-ionizing electromagnetic radiation (9 kHz-300 GHz). *Electronic Communications Committee (ECC) Recommendation/(02)04*. Radiocommunications Committee within the European Conference of Postal and Telecommunications Administrators.

Chen G. Y. and Lin C. H. (2007). Mobile handset and radiation power absorption. *IEEE Xplore,* **66:** 200-224.

Clipper. (2010). *Dielectric values.* Retrieved on 10th June, 2010 from Clipper Controls Incl.: http://www.clippercontrols.com

Damijan M., Natasa P., Francis H. (2006). *Electric properties of tissues*. Wiley Encyclopedia of Biomedical Engineering, John Wiley & Sons, Inc.

Damir K., KreSimir M., and Tomislav M. (2004). Measurement of mobile phone radiation in respect to human exposure standards. In: *46th International Symposium on Electronics,* ELMAR, Zadar, Croatia. pp. 515-519.

Dano M. (2002). Radiation shields vary in effectiveness. *RCR Wireless News,* **21**(19): 9.

Duff, W.G. (1976). A handbook on mobile communications. Don White Consultants, Inc.

FCC. (2010). *Wireless Devices and Health Concerns.* Retrieved June 20, 2010, from Federal Communications Commission: http://www.fcc.gov/guides/wireless-devices-and-health-concerns

FCC. (1997). Evaluating compliance with FCC guidelines for human exposure to radiofrequency electromagnetic fields. *OET Bulletin 65* (1997-2001): 55-58.

Frey A. (1998). Headaches from cellular telephones: Are they real and what are the implications? *Environmental Health Perspective,* **106:** 101-103.

Fröhlich H. (1980). The biological effects of microwaves and related questions. *Advances in Electronics and Electron Physics,* **53**:85–152.

Gianluigi M. and Alessandro D. (2008). An overall assessment of Mobile Internal Acquisition Tool. *Digital Investigations*, **12:** 121-127.

Goiceanu C. and Dănulescu R. (2006). Principles and methods of measuring environmental levels of electromagnetic fields. *Journal of Preventative Medicine,* **14**(4): 79-86.

Grundler W. and Kaiser F. (1992). Experimental evidence for coherent excitation correlated with cell growth. *Nanobiology,* **1**:163-176.

GSMA. (2007). *IMEI Allocation and Approval Guidelines.* Official document DG.06 V.3.4. GSM Association.

GSMA. (2009). *Specific Absorption Rate (SAR) Limits.* Retrieved February 16th, 2010, from GSM Arena: www.gsmarena.com/glossary.php3?term=sar

Guyton A. C. (1976). *Textbook of Medical Physiology* (5th ed.). W.B. Saunders, Philadelphia.

Honeywell. (2006). RF Exposure: SAR Standards and Test Methods. Honeywell International Inc. Skaneateles Falls, New York, U.S.A.

Hutter H. P., Moshammers H., Wallner P. and Kund M. (2006). Subjective symptoms, sleeping problems and cognitive performance in subject in living near mobile phone base stations. *Occupational Environmental Medicine,* **65**(5): 307-313.

Hyland G. J. (2000). Physics and biology of mobile telephony. *The Lancet,* **356:** 1833-1836.

ICNIRP. (1998). Guidelines for limiting exposure to time-varying electric, magnetic and electromagnetic fields (up to 300GHz). *Health Physics Society,* **74**(4): 494-522.

Icheln, C. (2001). *Methods for Measuring RF Radiation Properties of Small Antennas.* Electrical and Communications Engineering. Otamedia Oy: Helsinki University of Technology Radio Laboratory.

IEEE. (1999). IEEE Standard for Safety Levels with Respect to Human Exposure to Radio Frequency Electromagnetic Fields, 3 kHz to 300 GHz. IEEE Recommendation C95.1 p. 76.

IEGMP. (2000). Mobile phones and health. United Kingdom: National Radiological Protection Board.

INP. (2010). *Number analysis tools.* Accessed on 23rd May, 2010 from: http://www.numberingplans.com.

ITU. (1998). *The International identification plan for mobile terminals and users.* ITU-Technical Recommendations, ITU-T E.212**.** pp. 1-4.

ITU. (2009). *ITU Report for 2009: Kenya Poised for Huge Growth in Mobile Services.* International Telecommunications Union.

Jackson J. D. (1975). *Classical Electrodynamics* (2nd ed.). Wiley Eastern Ltd, New Delhi.

Jensen M., and Rahmat Y. S. (1995). EM Interaction of handset Antennas and a Human in Personal Communications. *IEEE Xplore*, **83**: 7-27.

JOVE. (2001). Radio Waves and the Electromagnetic Spectrum. *Teaching Tutorials*. Radio JOVE Educational Materials.

Kenneth L. (2010). *Periodic Table of Elements.* Retrieved on 12th June, 2010 from J.K. Barbalace Incl.: http://EnvironmentalChemistry.com

Kinsk, A. (2006). *Fundamentals of Antennas.* Retrieved May 21, 2010, from: www.mhproffessional.com/downloads/products/0071612882/0071612882_chap01.pdf

Kitchen, R. (2001). *RF and Microwave Radiation Safety Handbook.* Newnes.

Krewski D., Barry W., Riadh W., Brian H., Lotz W.. and Rosemonde M. (2007). Recent advances in research on radiofrequency fields and health: 2001-2003. *Journal of Toxicology and Environmental Health,* **10**: 287–318.

Lohn S., Ahlbom A., Hall P. and Feychting. (2004). Mobile phone use and the risk of acoustic neuroma. *Epidemiology.* **15:** 653-659.

Maneesh M., Anil P. K., Jayalekshmi H., Bhargav K. and Rohith V. (2009). Radio frequency electromagnetic radiation (RF-EMR) from GSM (0.9/1.8GHz) mobile phones induces oxidative stress and reduces sperm motility in rats. *Clinical Science,* **64**(6): 561-565.

Marshall B. (2001). *How Stuff Works. Cell Phones.* New York. NY, Hungry Minds, Inc. 2001, p.205.

Marshall B. (2002). *"How Cell Phones Work"*. HowStuffWorks Inc. Accessed on May 10th, 2010 from: http://www.howstuffworks.com

Masao T., Soichi W. and Kanako W. (2008). Characteristics, Dosimetry and Measurement of EMF. *IEEE Xplore,* **40**(4): 414-416.

Moneda A. P., Ioannidou M. P. and Chrissoulidis D. P. (2003). Radio-wave exposure of the human head: Analytical study based on a versatile eccentric spheres model including a brain core and a pair of eyeballs. *IEEE Transactions on Biomedical Engineering,* **50:**667–676.

NEMA. (2010). *Guidelines for E-Waste Management in Kenya.* National Environment Management Authority (NEMA), GoK: Ministry of Environment and Mineral Resources.

Nit H. (2007). *Electromagnetic radiation intensity profile from mobile phone base stations and subjective symptoms among office workers*. M.Sc Thesis. Mahidol University.

OECD. (2007). *The Economic Impact of Counterfeiting and Piracy*. Organization for Economic Cooperation and Development.

OSHA. (2010). *Radiation*. Retrieved June 11, 2010, from Occupational Safety & Health Administration: www.osha.gov

Paul M. (2005). *Forensic analysis of mobile phone*. B.Sc Thesis. Mawson Lakes, School of information and computer science.

Pederson G. F. and Anderson J. (1999). RF and ELF exposure from cellular phone handsets: TDMA and CDMA Systems. *Radiation Protection Dosimetry*, **83**, 131.

Rogier N. (2006). *CAMEL: Intelligent Networks for the GSM, GPRS and UMTS Network.* John Wiley & Sons Ltd.

Roosli M. (2004). Symptoms of ill health ascribed to electromagnetic field exposure –a questionnaire survey. *International Journal of Hygiene Evironmental Health.* **207**(2): 141-150

RPB. (2008). Export and Import control procedures. Radiation Protection Board of Kenya. Nairobi, Kenya.

Sandström M., Mild K. H., Wilén J. and Oftedal G. (1998). Symptoms associated with mobile phone use: Results of the Swedish-Norwegian Survey. *Occupational Medicine*, ***48***, 357-360.

Schiller J. (2003). *Mobile Communications* (2nd ed.). Dorling Kindersley Pvt Ltd, India.

Sin-Eng C. H. and Jit-seng T. (2000). Prevalence of headache among handheld cellular telephone users in Singapore. *Environmental Health Perspectives*, ***108***, 1059-1062.

SkyAuction. (2010). *Safe Guard Anti-radiation Protector Sticker for your cell phones*. Retrieved March 29, 2010, from http://www.skyauction.com/anyoffer/80629

Stefani H. and Dean C. H. (2009). The Power of cell phones. *Environmental Health Perspective Lesson*. (Jennifer K. C., Laura H. and Paul L., Eds.) National Institute of Environmental Health Sciences. pp.1-6.

Steve M. D. (1970). The electrical properties of cancer cells. Retrieved on June 20th, 2010 from: http://www.royalrife.com/haltiwanger1.pdf

STUK. (2009). *Measurements of mobile telephone radiation*. Retrieved February 20th, 2010, from Radiation and Nuclear Safety Authority:

http://www.stuk.org/radiation_monitoring/Regulation_of_mobilephones_sun_beds_and_laser/Measurements_of_mobile_phone_radiation/

TV. (2010). *Internal and External Cell Phone antenna booster*. Retrieved March 27, 2010, from TV: http://www.antennabooster.net/

Usikalu M. and Akinyemi M. (2007). Monitoring of radiofrequency radiation from selected mobile phones. *Journal of Applied Sciences Research*, **3**(12), 1701-1704.

Usman A. D., Wan W. F., Kadir Z. A. and Mokhtar M. (2009). Wireless Phones-Electromagnetic Field Radiation Exposure Assessment. *American Journal of Engineering and Applied Sciences*, **2**(4): 771-774.

WHO. (2000). Electromagnetic fields and public health:mobile telephones and their base stations. *Fact sheet No. 193*. World Health Organization, Geneva, Switzerland.

WHO. (2006). Model legistration for electromagnetic fields protection. World Health Organization, Geneva, Switzerland.

WHO. (2009). Electromagnetic radiation. *Etiology of Cancer*, **2**(12): 171-172.

Yoshihiro S. and Takahashi S. (2008). Material design of functionally graded plates with the function of electromagnetic noise suppression (Quantitative evaluation of the effect of electromagnetic noise suppression). *Journal of Solid Mechanics and Material Engineering*, **2** (7), 912-920.

APPENDICES

Appendix 1: General specifications of Broadband RF meter (NBM-550) and probe (EF-1891)

Device Product Name	**NBM-550**
Meter's Serial Number	B-0467
Meter's Calibration Due Date	2010/09/16
Recommended calibration interval	24 months
Immunity to radiated EMFs	200 Vm^{-1} (100 kHz to 60 GHz)
Applied Standard Name	ICNIRP 1998 general public
Batteries	Standard NiMH rechargeable batteries, 4 x type AA (Mignon), 2500 mAh
Operating time	At least 10 h
Weight basic unit	approx. 550 g (without probe and GPS receiver)
Probe Product Name	**EF-1891**
Probe Serial Number	A-0276
Probe Cal Due Date	2010/09/19
Probe Frequency Limit	3 MHz – 18 GHz
Probe E-field range	600.0 mV/m – 1.0 kV/m

Appendix 2: General specifications of Spectrum Analyzer (FSH18)

Spectrum analyzer model	FSH 18
Frequency range	10 MHz to 18 GHz
Reference frequency	10 MHz
Resolution bandwidth	*100 Hz to 1 MHz*
Detectors	Sample, max/min peak, auto peak, RMS
Reference level	-80 dBm to +20 dBm
Remote control interface	RS-232-C Optical interface
Weight	2.5 kg
Calibration Due Date	2010-09-20