

**DETERMINATION OF LEVEL OF RADIO FREQUENCY FIELD EXPOSURE
TO MILITARY PERSONNEL FROM TACTICAL FIELD EXPEDIENT
ANTENNAS**

BY

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THIS THESIS IS SUBMITTED TO THE UNIVERSITY OF GHANA,

SCHOOL OF NUCLEAR AND ALLIED SCIENCES,

DEPARTMENT OF NUCLEAR SAFETY AND SECURITY

**IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD
OF MASTERS OF PHILOSOPHY DEGREE (MPhil)**

IN

RADIATION PROTECTION

JULY, 2019

DECLARATION

This work is the result of research work undertaken by Justin Barnie Asamoah in the Department of Nuclear Safety and Security, Graduate School of Nuclear and Allied Sciences (SNAS), University of Ghana, under the supervision of Dr. Joseph K. Amoako and Dr. Philip Deatanyah.

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DEDICATION

I dedicate this thesis work to the Lord God Almighty for His divine grace, favour, guidance and protection throughout this period, to my parents the late - Ex WOI Asante Francis and Madam Mary Acheampong, my lovely wife, Mrs. Haggai Asamoah and my child Michael Acheampong Asamoah.

ACKNOWLEDGEMENTS

I wish to express my sincerest appreciation to my supervisors, Dr. Joseph Kwabena Amoako and Dr. Philip Deatenyah for their expert supervision, guidance, patience and encouragement. My profound gratitude goes to the Management of Radiation Protection Institute (RPI) of the Ghana Atomic Energy Commission (GAEC) for providing the available measuring instruments and its accessories for the research.

My sincere thanks also go to Dr. Irene Opoku Ntim of Nuclear Application Centre and Miss Sheila Gbormittah of Nuclear Regulatory Authority for their support and believing in me. I am also grateful to the Management of the National Communication Authority (NCA), especially Mr Peter Oyekwere and Mr Roland Kudozia for their assistance in diverse ways.

I am most grateful to the Director of Communications of the Ghana Armed Forces, Col. M. Essien for showing interest in my research and allowing me to conduct the field work. I am also grateful to all former and current Commanding Officers of both Signal Regiments and Signal Training School for their support and encouragement throughout the work.

Finally, I acknowledge all Staff of Signal Training School and especially Mr Daniel Nii Adjei for their support and assistance during the field work.

TABLE OF CONTENT

DECLARATION	ii
DEDICATION	iii
ACKNOWLEDGEMENTS	iv
TABLE OF CONTENT	v
LIST OF TABLES.....	vi
LIST OF FIGURES.....	vii
LIST OF PLATES.....	xi
ABSTRACT	1
CHAPTER ONE.....	1
INTRODUCTION	2
1.1 Background.....	2
1.2 Statement of Problem	3
1.3 Aim	4
1.4 Objectives	4
1.5 Justification and Relevance of the Work.....	5
1.6 Scope of Work/Limitations.....	6
1.7 Organisation of Thesis.....	5
1.8 Ethical Clearance.....	5
CHAPTER TWO.....	7
LITERATURE REVIEW	7
2.0 Background.....	7
2.1 Electromagnetic Radiation and its Applications.....	7
2.1.1 Theory of Electromagnetic Waves.....	8
2.1.2 The Electromagnetic Spectrum	9
2.2 Description and application of Military Radio Systems.....	10
2.2.1 High Frequency and Very High-Frequency Propagation.....	12
2.2.1.1 High Frequency (HF) Propagation.....	14
2.2.1.2 Very High and Ultra High Propagation.....	16
2.3.0 Field Expedient Antennas	18
2.3.1 Types and Pattern of Field Expedient Antenna.....	18
2.3.2. Whip Antenna.....	19
2.3.3 Inverted Vee	20

2.3.4 Horizontal Dipole	20
2.4.0 Exposure and interaction of radiofrequency from transmitting antennas	21
2.5.0 Power densities of transmitting antennas	21
2.5.1 Power density empirical studies	22
2.6.0 Calculation of Specific Absorption Rate (SAR).....	24
2.6.1 Specific Absorption Rate empirical studies	25
CHAPTER THREE	27
MATERIALS AND METHODS	27
3.1 Introduction.....	27
3.2 Materials	27
3.2.1 Anritsu Spectrum Analyser	28
3.2.2 Log Periodic Antenna	28
3.2.4 Garmin Oregon 200 GPS	29
3.2.4 The Phantom	30
3.2.5 The Tissue Equivalent Liquid.....	31
3.2.6 The Robot	31
3.3 Methodology.....	32
3.4 Sampling of the field measurements for power densities	32
3.4.1 Determination and Documentation of the Test point(s).....	33
3.4.2 Measurement of the electric field.....	34
3.4.2.1 Measurement of the Electric Field Around a Base Station.....	35
3.4.2.3 Measurement of the electric field around antennas on manpack radios	36
3.4.2.4 Measurement of the electric field around antennas on vehicle-mounted radios	36
3.4.3 Determination of field strength and power density	37
3.4.4 Uncertainty Estimation.	39
3.4.5 Exposure Quotient.....	40
3.5 Measurement for Specific Absorption Rate (SAR)	40
CHAPTER FOUR	42
RESULTS AND DISCUSSION	42
4.1 Introduction.....	42
4.2 Radiating antenna used as a Base Station.....	42
4.3 Radiating antenna from a Manpack Radio	43
4.4 Radiating antenna effect in the Operations Room	44
4.5 Radiating antenna of a Vehicle-Mounted Antenna	45

4.6 Exposure Quotient	46
4.7 Specific Absorption Rate Measurement of Radio_4HH	47
4.8 Comparison with International Standards	48
4.8 Comparison of results with other researched works.....	50
CHAPTER FIVE	52
CONCLUSION AND RECOMMENDATIONS	52
5.1 Conclusion	52
5.2 Recommendations.....	53
5.2.1 Recommendation to Directorate of Communication	53
5.2.2 Recommendation to Occupationally Exposed Workers (Radio Operators and Technicians).....	53
5.2.3 Recommendation to the General Public (Troops).....	54
5.2.4 Recommendation for Further Studies	54
REFERENCES	55
APPENDICES	58

LIST OF TABLES

Table 2. 1 Typical sources of electromagnetic fields.....	13
Table 2.2 Examples of emissions in the frequency band from 9 kHz to 300 GHz	14
Table 4.1 Estimated exposure quotient from measured electric field strength.....	47
Table 4.2 SAR measurement of Radio_4HH.....	48
Table 4.3 Maximum measured safety distance for workers.....	49

LIST OF FIGURES

Fig 2. 1 Electromagnetic Field.....	8
Fig. 2.2 Directional energy flux of an electromagnetic field (Poynting Vector,S).....	9
Fig 2.3 Electromagnetic Spectrum	10
Fig 2.4: Tactical ground-based radio (manpack).....	11
Fig 2.5 Military Field Expedient Antenna System.....	12
Fig 2.6: Ground wave propagation.....	15
Fig 2.7: Skywave propagation.....	16
Fig 2.8: Radiation Pattern of Whip Antenna.....	19
Fig 2.9: Vertical Whip on Vehicle.....	19
Fig 2.10: Forward Bent Whip on Vehicle.....	20
Fig 2.11: Backwards Bent Whip on Vehicle.....	20
Fig 2.12: Inverted Vee Antenna Elevation Radiation Patterns.....	20
Fig 2.13: Center-Fed Horizontal Dipole.....	21
Fig 2.14: Horizontal Dipole Antenna, Elevation Radiation Patterns.....	21
Fig 2.15: RF/MW exposure of military career personnel in Poland.....	24
Fig 3.1 Anritsu Spectrum Analyser.....	28
Fig 3.2 Log Periodic Antenna.....	29
Fig 3.3 Garmin Oregon 200 GPS.....	30
Fig 3.4: Phantom.....	30
Fig 3.5 Robot.....	31
Fig. 3.6 Shows the coordinates and test points of Signal Training School radiating antenna using the Google earth.....	34
Fig 3.7 Spectrum location base station radio antenna radiating at 5.52 MHz.....	35

Fig 3.8 The test configuration of a DUT SAR evaluation.....	41
Fig. 4.1 Plot of Electric Field Strength against Distance (Base Station).....	43
Fig. 4.2 Plot of Electric Field Strength against Distance (Manpack).....	44
Fig. 4.3 Plot of Electric Field Strength against locations in Operations Room.....	45
Fig. 4.4 Plot of Electric Field Strength against Seating Positions in Military Vehicle...	46
Fig. 4.5 Plot of SAR (W/Kg) against depth, Z (mm) for Radio _4HH.....	48
Fig 4.6 Plot of Electric Field Strength against Frequency showing compliance for Occupational and General public exposure.....	49

LIST OF PLATES

Plate 3.1 Measurement instrumentation.....	31
Plate 3.2:Manpack radio in use by a soldier.....	35
Plate 3.3 A typical radiating antenna on a military vehicle.....	36

ABBREVIATIONS

SAR	Specific Absorption Rate
NCA	National Communication Authority
GAEC	Ghana Atomic Energy Commission
DUT	Device Under Test
GAF	Ghana Armed Forces
ICNIRP	International Commission on Non-Ionizing Radiation Protection (ICNIRP)
EMF	Electromagnetic Field
FM	Frequency Modulation
HF	High Frequency
VHF	Very High Frequency
UHF	Ultra High Frequency
EHF	Extremely High Frequency
EW	Electronic Warfare
SCR	Single Channel Radio
NVIS	Near Vertical Incidence Skywave Propagation
ELF	Extremely Low Frequency
STS	Signal Training School
TV	Television
MRI	Magnetic Resonance Imaging
AM	Amplitude Modulation
PMR	Private Mobile Radio
DECT	Digital Enhanced Cordless Telephone
USA	United States of America
GSM	Global System for Mobile Communication

UMTS	Universal Mobile Telecommunication Service
RTC	Radio Transmitting Centre
MW	Microwave
IEEE	International Electrical and Electronic
GPS	Global Position Syatem
FCC	Fideral Communication Commission
DAT	Digital Audio Tape
JPEG	Joint Photographic Expert Group
DUT	Device Under Test
SSB	Single Side Band
RPO	Radiation Protection Officer
AGNIR	Advisory Group on Non -Ionising Rdaiation
FM	Frequency Modulation
GHz	Giga Hertz

SYMBOLS

ρ	Density
σ	Conductivity of the tissue in siemens per meter
ω	Angular velocity
λ	Wavelength
f	Frequency
v	Velocity
c	Speed of light
B	Magnetic Field
E	Electric Field
S	Poynting Vector
μ_0	Permittivity of free space

ABSTRACT

Radio communication is an integral part of any military operation. This helps commanders at all levels to achieve command and control in their operational environment. The employment of these radios with their corresponding antennas has led to an increase in the concern of the potential health risks that may arise as a result of exposure to radio frequency (RF) radiations. The main objective of this research was to determine the levels of radio frequency field exposure to military personnel from tactical expedient antennas. The electric field strength and Specific Absorption Rate (SAR) of selected military radio antenna were measured at various distances from radio antennas locations in the Burma Camp barracks and analysed during real-time transmission. The radios antennas were selected based on their employment in the field of operations: base station, manpack vehicle mount and handheld (SAR). At a transmission frequency of 5.52 MHz, the maximum power density measured for the base station, manpack and vehicle-mounted radiating antennas were $9.05 \times 10^{-7} \text{ W/m}^2$, $3.359 \times 10^{-4} \text{ W/m}^2$ and $4.23 \times 10^{-6} \text{ W/m}^2$ respectively. The general public and occupational exposure quotients for base station radiating antenna were 3.22×10^{-9} and 1.67×10^{-10} , manpack were 7.14×10^{-2} and 3.22×10^{-9} and vehicle mounted were 9.71×10^{-3} and 2.67×10^{-14} respectively. The SAR value for the handheld radio antenna was measured to be SAR 0.19 W/Kg for 10g and 0.31 W/Kg for 1g of tissue with a peak SAR of 0.46 W/Kg at the surface of the tissue. The results obtained for both the field and laboratory measurements were found to be in compliance with the International Commission on Non-Ionizing Radiation Protection (ICNIRP) RF exposure limit

CHAPTER ONE

INTRODUCTION

1.1 Background

Military all over the world use communication systems to facilitate their operations either by land, air or sea. The military, as well as other security services, also use some portions of the electromagnetic spectrum to send and receive information between military systems in a flexible way (Gherman, 2015). In view of this, accessing the spectrum is vital for modern military operations especially Electronic Warfare (EW). The electromagnetic spectrum is a continuum of all electromagnetic waves arranged according to frequency and wavelength (Halit and Wei-Juet, 2006). The spectrum has several applications to the military communications and surveillance systems. Some of the areas include submarine communications, long and short distance voice, aircraft and space communications, radio relayed telephone communications, radio navigation radar, meteorological aids, and in the field of medicine. While the Army uses it in the implementation of some weapons, surveillance devices as well as radio communication, the Airforce uses it in air traffic control systems and the Navy rather has interest in the Extremely Low-Frequency portion (ELF) of the spectrum for the establishment of experimental systems, for submarine communications.

All these useful applications of the spectrum can also be potentially hazardous to human health if not properly controlled. The military's involvement in the exploitation of the electromagnetic spectrum use of certain frequency bands sometimes overlaps the band used by civilian agencies in the areas of FM broadcasting and television station installations. The use of these frequency bands by the military involves systems ranging in power output from a few milliwatts to several megawatts. These are the driving force behind various radio communication systems.

Military communication uses radio frequencies and microwaves. The transmitting antennas emit these waves in the form of electromagnetic energy (Dawoud, 2003). These electromagnetic energies are characterized by frequency (Hertz) and wavelength (m). Radio frequency (RF) waves occupy a range of 3 kHz to 300 GHz (Schilling, 1999). Microwaves frequency range from 1 GHz to approximately 100 GHz. The most commonly used radios by the military for communication are the Motorola base station (handheld), the Barret, Codan, and the PRC 146 Manpack radio. These radios are usually deployed in the field and operated within the High Frequency (HF) and Very High Frequency (VHF) RF ranges of the electromagnetic spectrum. They are transmitters and receivers of the radio signal and therefore are also known as transceivers. The antenna of these transceivers generates electromagnetic fields (EMF) which pose several dermatological symptoms such as burning sensations, redness, and tingling as well as neurovegetative symptoms such as fatigue, headache, concentration difficulties, nausea, heart palpitation (SCENIHR, 2006) to troops deployed for routine work. The field expedient antennas of these transceivers usually make use of skywave or ground wave propagations which are either omnidirectional or directional (point-to-point). The electromagnetic radiations emitted from these antennas are used to transmit voice communication between military units and to intercept enemy communication. Military Units deployed in the field for tactical exercises, peacekeeping missions or battlefields, communicate mostly by using the HF and VHF.

1.2 Statement of Problem

Radiofrequency usage is prevalent in the military line of duty and operations especially in the area of electronic warfare. This includes application in both short- and long-range communications systems. Most of the military radio -operators or Radio technicians are

exposed at the near-field zone of RF/MW emitting devices at different exposure levels.

Additionally, exposure conditions are frequently altered by these operators and technicians in the course of duty. These normally happen when radio operators or RF/MW technicians vary parameters of the emitting antennas or introduce another RF device while at work. Soldiers at sentry posts usually hang their handheld radios at the left breast pockets or the waist levels of the uniforms while on duty. The potential risk is that these operators' radios sit in the radio room or (the sentries) hang the radios on them throughout their tour of duty while radio transmissions are in progress. These can result in inhomogeneous absorption of RF energy in the operator's body. Even though most military personnel

are unconscious of the potential health risk associated with direct contact with these antennas, a few of them complain to their colleagues of some perceived effects. This makes it necessary to conduct this work to provide scientific information to ascertain whether these complaints are genuine.

1.3 Aim

The aim of this study is to determine the level of exposure from field antennas of selected military radios and to influence policies for the military in radio communication.

1.4 Objectives

The objectives include:

- To determine the effect of the power densities of military transmitting field expedient antennas at various distances from an operator or RF technician.
- To measure and estimate the specific absorption rate(SAR) in the individuals

exposed to the RF fields from the near fields of the radio antennas

- To determine the potential hazards of these fields to the exposed body parts of the operators or the RF technicians.
- To compare the measured levels to the limits set by the International Commission on Non-Ionizing Radiation Protection (ICNIRP) adopted by Ghana.
- To make appropriate recommendations for the installations and employment of military field radiating antennas.

1.5 Justification and Relevance of the Work

The military has many communication systems (other than satellite) with long ranges. Most part, single-channel, point-to-point voice, and teletype communications are carried out in the Medium and High-frequency band (although some long-range maritime communications occur in the Low Frequency and Very Low-Frequency bands) while multiple channels, radio relay voice, and data communications occur in the microwave bands.

Although power output of most military equipment in the ranges above 33 MHz is relatively low, there is still some potential hazards associated with these systems even under the present safety standards. Furthermore, the study was to create awareness on the health-related implication of the transmitting military antennas pose to operators and technicians. Besides, it will also help the technician to know the safety distances and protective measures to take when working on these antennas and other military communication equipment.

In the Ghana Armed Forces, there are limited studies on the power densities of the various

military radios (both HF and VHF) and their effect on military personnel. No work has been done on the hazards of radiating field expedient antennas in the Ghana Armed Forces. The research would indeed be a good way of how much EMR is emitted from the antennas, reducing a substantial dose of radiation that may interact with the human body thereby avoiding associated health problems and could serve as a means of providing vital scientific information which may influence the uses and operations of military radios nationwide.

1.6 Scope of Work/Limitations

This work focuses on measuring the power density (W) of radiations emitted from the various field antennas used by troops both in the barracks and on the field. The Specific Absorption Rate of the radiation on the tissues of the operators/repairers was also calculated. The research was limited to military field-expedient radio and antennas (Barret, Motorola, Codan, and PRC 146 Manpack Radios) used by the Ghana Armed Forces. In practice; the assessment of exposure for operators/repairers of RF/MW for this research was limited to the management of field power density (W) to evaluate SAR.

1.7 Organisation of Thesis

This work is arranged chronological order of five chapters. Chapter one gives a brief introduction to the research work. Chapter two reviews the existing literature on the research topic. Chapter three focuses on the materials and methodology employed in the study. The results and discussion are presented in chapter four, with the chapter five presenting the conclusion, recommendation and recommendations for further studies.

1.8 Ethical Clearance

This ethical clearance was waved because the study of emissions patterns of the various military tactical radio antennas from the Ghana Armed Forces, their employment and results obtained are solely for research purposes.

CHAPTER TWO

LITERATURE REVIEW

This chapter reviews some literature in the fields of electromagnetic radiation and its application. It provides an overview of the electromagnetic spectrum; a description of the military radio systems and field expedient antennas; reviews relevant methodology to determine power density levels, specific absorption rate (SAR) and exposure levels of exposure of some specific radio frequencies with the standard set by the International Commission on Non-Ionizing Radiation Protection (ICNIRP).

2.0 Background

Military Communication Systems such as hand-held radios, vehicle-mounted radios and field antennas emit relatively low power compared to satellite transceivers. Notwithstanding, these equipment are used near the human body, there is the likelihood that there would be radiation exposure.

2.1 Electromagnetic Radiation and its Applications

Electromagnetic radiation has always been with us. They travel through vacuum as well as through air and other substances (Collision, Kirkby and Macdonald, 2003). Electromagnetic radiation refers to the wave-like mode of transport in which energy is carried by electric (E) and magnetic (H) fields vectors that vary in planes perpendicular to each other and to the direction of energy propagation (Novotny, 2013) as indicated in Fig 2.1. While the risk associated with electromagnetic radiation (ER) is low, some are essential to life: radio waves and microwaves make life easier. Electromagnetic waves are produced by oscillating electric charges that give off photons. Unlike mechanical waves

such as the ocean or sound waves, electromagnetic waves can transfer energy without a medium.

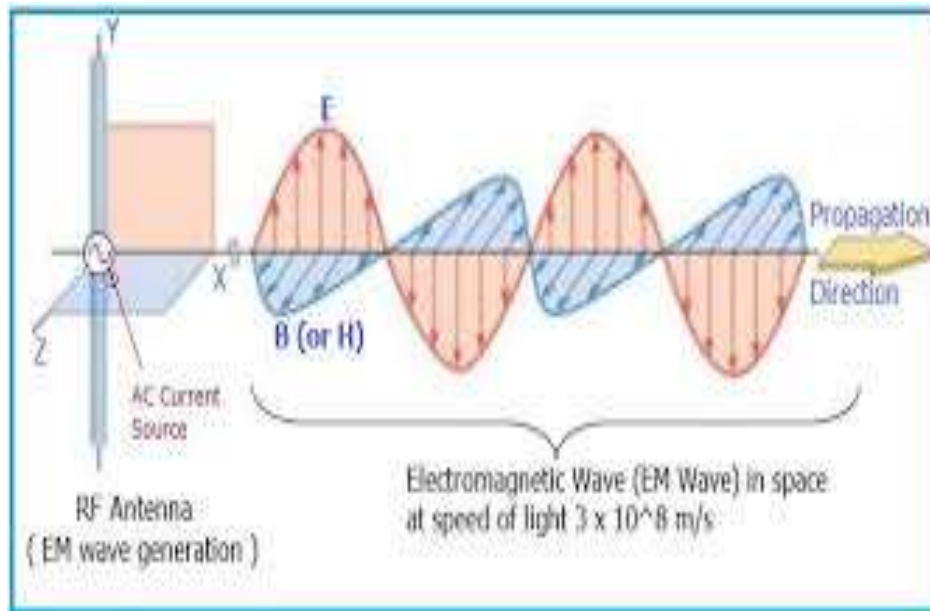


Fig 2.1: Electromagnetic Field

2.1.1 Theory of Electromagnetic Waves

From the plane wave in Fig 2.1, the harmonic EM wave below are considered:

$$E(x, t) = E_{max} \cos(kx - \omega t) \dots \dots \dots 1$$

$$B \text{ or } H(x, t) = B_{max} \cos(kx - \omega t) \dots \dots \dots 2$$

where $k = 2\pi/\lambda$ is the wavenumber, $\omega = 2\pi f$ is the angular frequency, λ is the wavelength(m), f is the frequency(Hz) and $\omega / k = \lambda f = v = c$. . Taking partial derivatives of E and B/H and substituting into (1):

$$\frac{\partial E}{\partial x} = -kE_{max} \sin(kx - \omega t) \text{ and } \frac{\partial B}{\partial t} = \omega B_{max} \sin(kx - \omega t) \dots \dots \dots 3$$

$$-kE_{max} \sin(kx - \omega t) = -\omega B_{max} \sin(kx - \omega t) \dots \dots \dots 4$$

$$E_{max} = \frac{\omega}{k} B_{max} = c B_{max} \dots\dots 5$$

$$c = \frac{E}{B} \dots\dots 6$$

The ratio of the electric field to the magnetic field in an electromagnetic wave at every instant equals the speed of light. The rate of energy transfer by an electromagnetic wave is described by the *Poynting* vector, $\vec{S}$, which is defined as the rate at which energy passes per a unit time through a surface area perpendicular to the direction of the wave propagation (W/m^2): $\vec{S} = \frac{1}{\mu_0} \vec{E} \times \vec{H}$. This is indicated in Fig 2.2

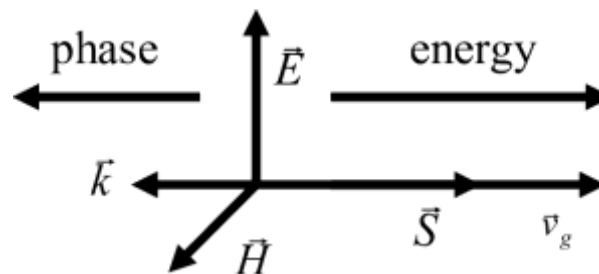


Fig 2.2 Directional energy flux of an electromagnetic field (Poynting Vector, $\vec{S}$)

2.1.2 The Electromagnetic Spectrum

The electromagnetic spectrum describes a group of distinct energy forms that stem from various sources (Aghaei, Thayoob, Mahdaviasl, Darzi and Imamzai, 2012). The energies released are characterized by wavelength and frequency. The regions of high frequencies and penetrating power are gamma rays, X-rays and ultraviolet light; lower frequencies of the spectrum include microwaves and radio waves (Mann and Raschke, 2004). Fig 2.2 describes the electromagnetic spectrum. At sufficiently high frequencies (energies), the radiation can break the bonds between atoms and electrons, hence such radiation is named ionizing radiation. Radiation of energy less than 13.6 eV is, on the other hand, is termed nonionizing radiation because it cannot eject this most easily removed electron (Ritenour & Hendee, 2002). These are mainly optical radiation (infrared radiation, visible light, and

ultraviolet radiation). The use of the electromagnetic spectrum is prevalent in the military in the area of electronic warfare. The electromagnetic spectrum is used in an increased number of military systems such as radar-guided weapons and surveillance devices. According to (Gherman, 2010), without spectrum, we cannot imagine network-centric warfare in the information age. A lot of sensors are based on the electromagnetic spectrum in order to obtain a live image of the modern battlefield.

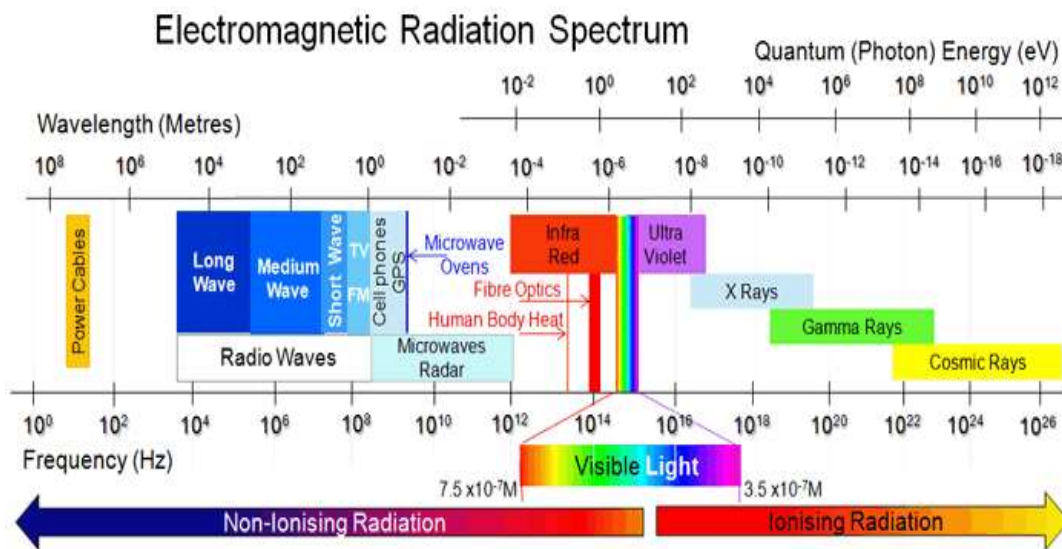


Fig 2.3: Electromagnetic Spectrum

2.2 Description and application of Military Radio Systems

The use of military radios also called Single Channel Radios (SCR) spans from pre-historical times to date. They are basically tactically ground-based, tropospheric scatter as well as naval or on board radios as indicated in Fig 2.4. This research focuses more on the radio systems used by the army (tactically ground-based). The military radios (be it HF/VHF) consist of a transmitter, transmission line (coaxial cable), receiver and antenna. The radios are designed such that the transmitter also acts as a receiver. They are the main means of communications support for maneuver units (Rhodes, 1998). They are combat radios that serve as the primary means of communications for command and control and

fire support on the battlefield. Single Channel Radios (SCR) with their antennas are employed as hand-held, manpack, vehicle-mounted, bench-mounted, and sheltered radios. Tactical SCRs usually operate in the three military radio frequency bands (high frequency [HF], very high frequency [VHF], and ultra-high frequency [UHF]).



Fig 2.4: Tactical ground-based radio (manpack)

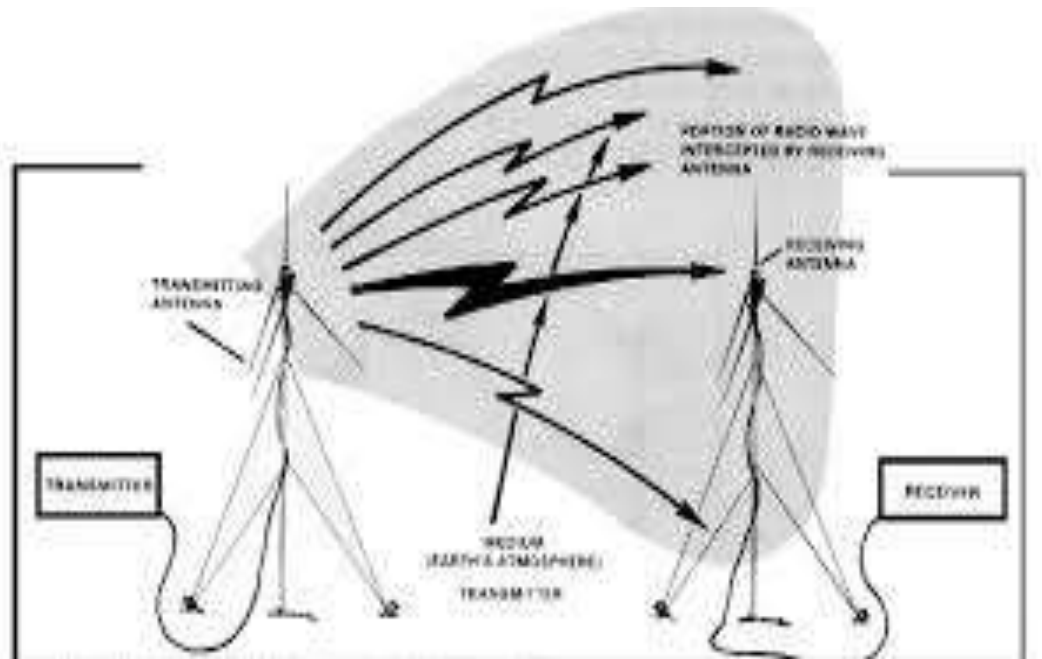


Fig 2.5 Military Field Expedient Antenna System

2.2.1 High Frequency and Very High-Frequency Propagation

Wave propagation is the process by which radio signals are transmitted through the atmosphere from one antenna to the other. This section briefly describes the propagation factors needed to be known to better understand the antenna information. This part is divided into High Frequency (HF) and Very High Frequency (VHF) propagation.

Table 2.1. Typical sources of electromagnetic fields (SCENIHR, 2006)

Frequency range	Frequencies	Some examples of exposure sources	Examples of maximal intensities
Static	0 Hz	VDU (video displays); MRI and other diagnostic /scientific instrumentation; Industrial electrolysis;	70 μ T 1 T in the tunnel; 200 mT at the gate; < 0.5 mT outside the device room 10-30 mT at the level of the feet
ELF	0-300 Hz	Power lines; Domestic distribution lines, Domestic appliances; Electric engines in cars, train; Welding devices	10-20 μ T under the line, or 10 kV/m < 0.1-0.2 μ T (microteslas) in the room 50 μ T and 300 V/m
IF	300 Hz – 3 kHz	VDU; anti-theft devices in shops, hands-free access control systems, card readers and metal detectors; MRI; Welding devices	30 to max 700 nT 10 V/m
RF	3 kHz– 300 GHz	Mobile telephony; Broadcasting and TV; Microwave oven; Radar, portable and stationary radio transceivers, personal mobile radio; MRI	0.1 W/m ² 0.5 W/m ² 0.2 W/m ²

Table 2.2 Examples of emissions in the frequency band from 9 kHz to 300 GHz (ECC, 2004)

Symbol	Frequency Range (lower limit exclusive, upper limit inclusive)	Services
VLF	9 to 30 kHz	Induction heating
LF	30 to 300 kHz	Industrial induction heating, AM broadcasting, clock transmitters
MF	300 to 3 000 kHz	AM radio, industrial induction heating
HF	3 to 30 MHz	Broadcasting, Radio-amateurs, Armed Forces
VHF	30 to 300 MHz	PMR, TV, Armed Forces, Radio-amateurs, FM broadcasting, Aeronautical Services
UHF	300 MHz to 3 000 MHz	TV, GSM, DCS, DECT, UMTS, Bluetooth, earth station, Radars
SHF	3 to 30 GHz	Radars, Earth stations, Microwave links
EHF	30 to 300 GHz	Radars, microwave links

2.2.1.1 High Frequency (HF) Propagation

HF(2-30 MHz) provide long-range and worldwide communication through the ionosphere (Raab et al, 2002)). Over the years, the theory of HF communications and its military applications have been described in various US Army technical and field manuals which today have culminated in publications such FM 24 -18 (Field Radio Technique), TM 1-666 (Antenna and Radio Propagation). All these publications place primary emphasis on what in the past has been the most useful modes of HF radio propagation for military purposes. (Fiedler &Hagn,1983). These- modes include a ground wave or skywave propagation. The Ground wave propagation which consists of Direct, Space and reflected waves as shown in Fig 2.6.

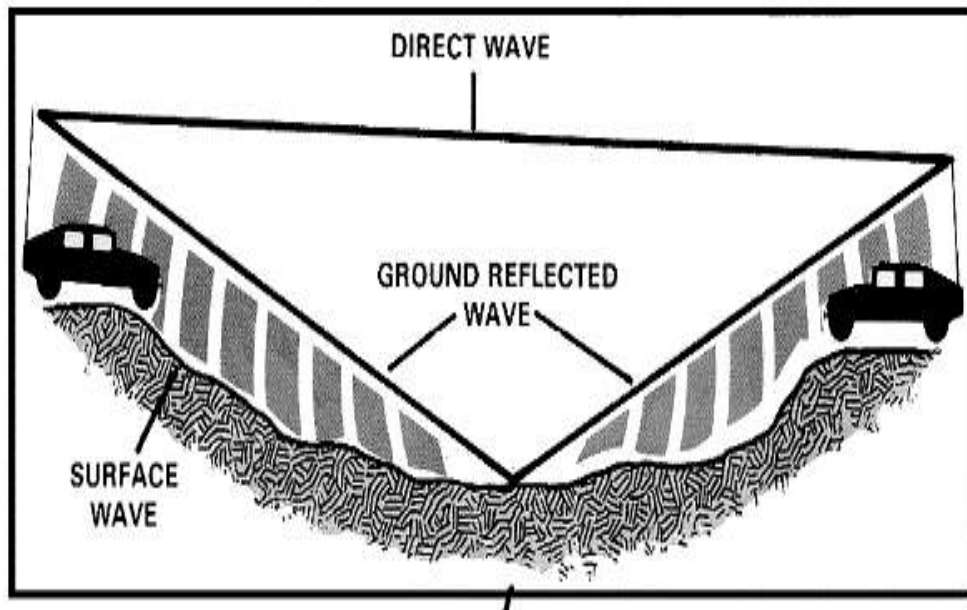


Fig 2.6: Ground wave propagation

The skywave propagation uses the ionosphere to transmit radio signals to a receiving station. Commanders in a battlefield or barracks are to achieve effective long-range communication between units HF radios using skywave propagation. An investigation of the Near Vertical Incidence Skywave Propagation (NVISP) was conducted to measure the angles of elevation and optimum antenna height for horizontal dipole antennas (Witvliet, Maanen, Petersen and Westenberg, 2015). In this research, the different characteristic layers of the ionosphere (D, E, and F) were explained into details as shown in Fig 2.7.

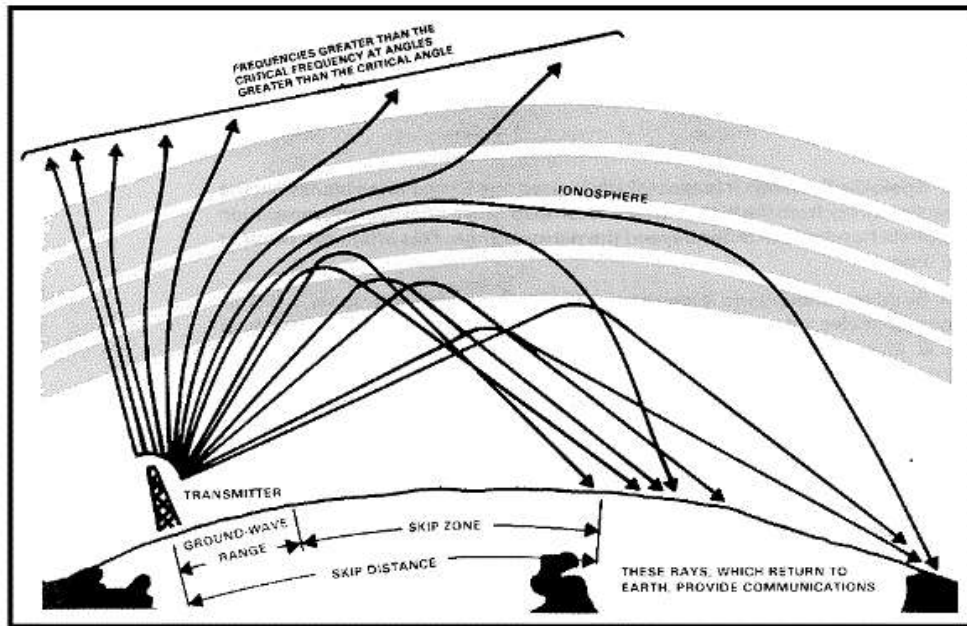


Fig 2.7: Skywave propagation

All these modes of propagation are very useful to the military during tactical exercises or real-time battlefield exposure. Different field expedient antennas which are normally constructed to produce different radiation patterns. This depends on the positioning of the antenna and the type of communication one wants to achieve. These radiation patterns are within an electromagnetic field set up by the antenna being used. However, the operators or the RF technicians working with the antennas consequentially find themselves also in the field and the electromagnetic field interact with their bodies.

2.2.1.2 Very High and Ultra High Propagation

The transmission powers used for broadcasting in the VHF (30-300 MHz) and UHF (300-3 GHz) bands vary widely according to the area and terrain over which coverage is to be provided. VHF transmissions are easily affected by terrain conditions, and shadowed areas with poor signal strength

such as behind hills and in valleys. For this reason, in addition to the main set of high-power transmitters, large numbers of local booster transmitters (repeaters) are needed to receive signals from the main transmitters and rebroadcast them into shadowed areas.

A measurement made in the field could range from tens to hundreds of volts per meter within broadcast towers, but it is not clear how representative these spot measurements are to typical worker exposure (ICNIRP, 2009a). Instruments are worn on the body as a personal dosimeter to measure electric and magnetic field strengths during work activities at a transmitter site (Cooper et al, 2004). They reported that a wide temporal variation in field strengths was typically found within any single record of exposure to electric or magnetic fields during work on a mast or tower used for high-power VHF/UHF broadcasts. The highest instantaneous exposures usually (Cooper et al, 2004) occurred when the subject was in the locality of high-power VHF antennae or when a portable VHF handheld radios were used to communicate with other workers.

A report which studied population exposure in the USA conducted by (Mantiply et al, 1997) during the 1980s, was based on spot measurements at selected outdoor locations. An estimated 50 %, 32 % and 20 % of the population were exposed to levels greater than 0.1 V/m from VHF radio, VHF television and UHF television signals, respectively. At levels greater than 2 V/m, VHF radio and television contributed 0.5 % and 0.005 % of the population exposure, while UHF television contributed to 0.01 % of the population exposure at levels greater than 1 V/m.

Another investigation was also conducted on the field strengths associated with VHF/UHF radio and television broadcast signals of some 200 statistically distributed locations in residential areas around Munich and Nuremberg in Germany (Schubert et al, 2007). The study was to investigate whether the levels had changed as a result of the switch-over from

analogue to digital broadcasting, and measurements were made before and after this change occurred at each location. The median power density levels were $0.3 \mu\text{W}/\text{m}^2$ (11 mV/m) for the analogue signals and $1.9 \mu\text{W}/\text{m}^2$ (27 mV/m) for the digital signals. FM radio signals had median power density levels of $0.3 \mu\text{W}/\text{m}^2$ (11 mV/m), like the analogue television signals, and the values ranged over approximately two orders of magnitude on either side of the medians for all types of the broadcast signal. It is worthy to note that these values are lower than those reported in the USA during the 1980s.

2.3.0 Field Expedient Antennas

Field expedient antennas provide a way to dog -tire the enemy's electronic warfare efforts. One such typical field-expedient bi- or uni-directional antenna could intercept and be used to prevent the enemy interception of transmissions. There are three types of antenna according to their directional characteristics. These are Omni (all directions), bi (any two directions) and unidirectional (any one direction).

Tactical antennas are specially designed to be rugged and permit mobility with the least possible sacrifice of efficiency. They are also designed to be rapidly deployed in tactical military operations and disaster or relief situations such as flood or earthquake. During military operations, they are mounted on the sides of vehicles that have to move over rough terrain; others are mounted on tops of single masts or suspended between sets of masts. The smallest antennas are mounted on the helmets of personnel who use the radio sets or mounted on low powered radios for foot patrols.

2.3.1 Types and Pattern of Field Expedient Antenna

There are varieties of antennas used for military communication. All these varieties depend on the operational situation. Some of the commonly used antennas by the Armed Forces

are a whip, inverted V (or drooping), horizontal dipole and horizontal log periodic antennas. More detail information is provided by (Harris, 2005).

2.3.2. Whip Antenna

The vertical whip antenna is ideal for ground wave propagation since it is omnidirectional (Janek and Evans, 2010). It has low take-off angles and is polarized vertically. The typical vertical whip radiation pattern is shown in Fig 2.8. For instance, there is virtually no power being radiated off the top of the antenna. From the chart below the doughnut shows the radiation pattern and gain of the antenna at the various take-off angles. The radiation pattern for a vehicle with a vertical whip is shown in Fig 2.8. The null (hole) in the overhead pattern for this vehicular configuration is clearly shown. A tilt-whip adapter is an easily deployable mechanism that allows the antenna to be bent over at several angles to modify the radiation pattern to be ideal for skywave operation. Bending the whip forward over the vehicle results in the null being filled in as in Fig 2.10. Whenever the whip is bent backwards away from the vehicle results in the pattern shown in Fig 2.11, an even more omnidirectional NVIS-type pattern, but obviously not practical for vehicles in motion.

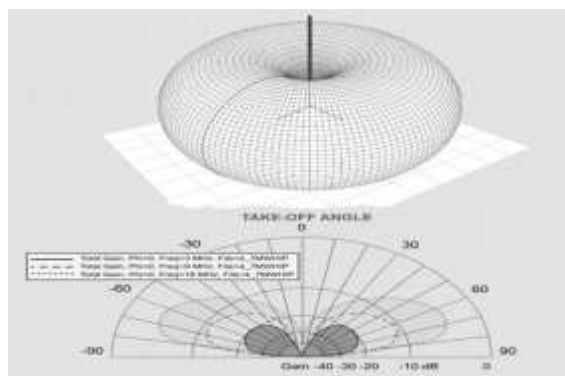


Fig 2.8: Radiation Pattern of Whip Antenna

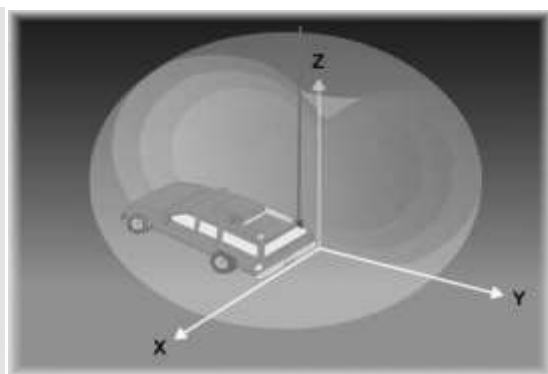


Fig 2.9: Vertical Whip on Vehicle

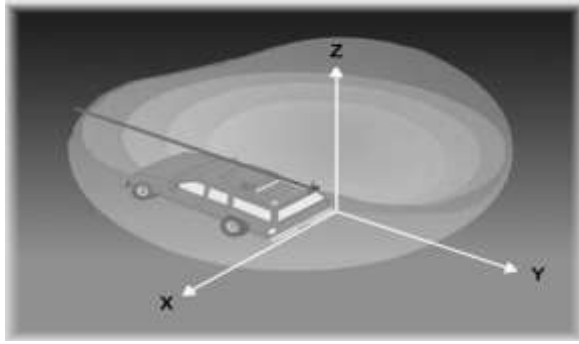


Fig 2.10: Forward Bent Whip on Vehicle

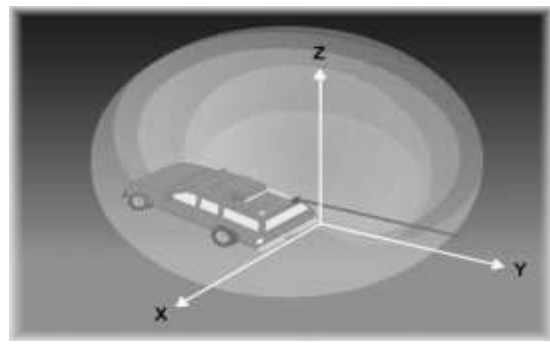


Fig 2.11: Backwards Bent Whip on Vehicle

2.3.3 Inverted Vee

An inverted Vee (Kuch, 1984), which is also called drooping dipole offers a combination of horizontal and vertical radiation with omnidirectional coverage as indicated in Fig 2.12.

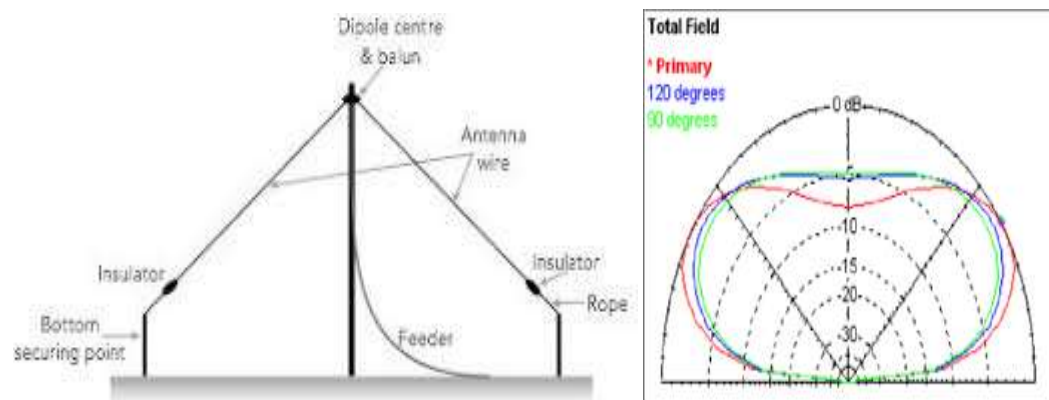


Fig 2.12: Inverted Vee Antenna Elevation Radiation Patterns

2.3.4 Horizontal Dipole

The half-wave dipole is one of the most used HF antenna. This is basically a length of wire equal to one-half the transmitting wavelength and excited in the centre. The dipole can be oriented to provide either horizontal or vertical polarization. Fig 2.13 shows a centre-fed horizontal dipole antenna. The radiation pattern can change dramatically as a function of its distance above the ground. Fig 2.14 shows the elevation radiation patterns of a horizontal dipole for several values of its height (in terms of transmitting wavelength) above the ground.

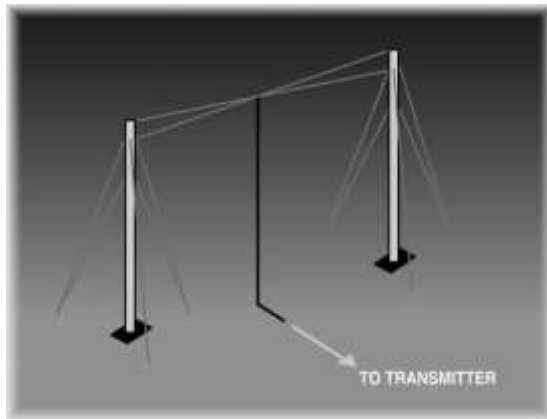


Fig 2.13: Center-Fed Horizontal Dipole

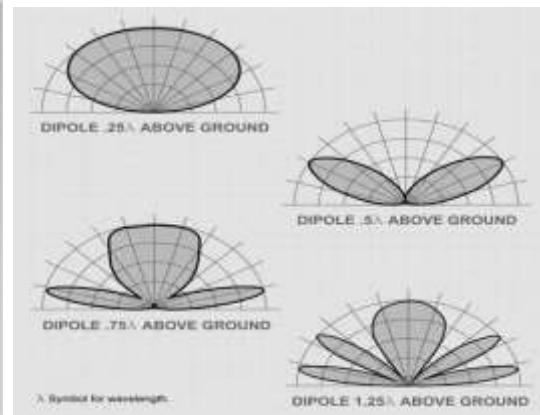


Fig 2.14: Horizontal Dipole Antenna, Elevation Radiation Patterns

2.4.0 Exposure and interaction of radiofrequency from transmitting antennas

People are exposed both at home and at work to electric and magnetic fields arising from a wide range of sources that use RF electrical energy (AGNIR, 2003). There are two sources of radiofrequency radiation exposure from the mobile telephone system: base station antennas and the mobile telephone or handset (Al-Bazzaz, 2008). Exposure from the base station antennas is continuous, irradiates the whole body and exposes an entire community in different ways according to relative positions and separation distances. Exposure from the handset to the head is more intense (Kreis et al, 2013). It only for intermittent periods and exposure intensity and duration tends to be the user's responsibility.

2.5.0 Power densities of transmitting antennas

Power density (S) as explained in (ITU-T, 2004) is the power per unit area normal to the direction of electromagnetic wave propagation, usually expressed in units of Watts per square meter (W/m^2).

From Maxwell's equations for the electric and magnetic fields for a localized oscillating source, such as an antenna, surrounded by a homogeneous material (typically vacuum or air), the relationship between the Electric field and Power density is

$$S = \frac{E^2}{\eta} = \frac{E^2}{120\pi} = \frac{E^2}{377} \dots \dots \dots 7$$

Where S is the power density in watts per square meter.

E is the electric field strength in volt per meter.

η is 377ohms is the characteristic impedance of free space

2.5.1 Power density empirical studies

Although there are various publications on the estimated and measured values of the radiofrequency radiation power density around cellular base stations, such cannot be said of tactical expedient antennas used by the military. Research conducted by (Miclaus and Bechet, 2006) discussed the possibilities of exposure assessment due to RF GSM BSA emissions in Romania. The results gave an indication of a simplified calculation of human exposure next to a BSA (near and far-field). The power density peak values measured in 3 locations were $S_1^{peak} = (9.66 \pm 2.73) \times 10^{-5} \text{ W/m}^2$, $S_2^{peak} = (23.00 \pm 5.51) \times 10^{-5} \text{ W/m}^2$ and $S_3^{peak} = (62.00 \pm 13.54) \times 10^{-5} \text{ W/m}^2$ which were well below the ICNIRP references.

Similar research by (Baltrenas and Buckus, 2011) was conducted to measure indoor power density close to a GSM 900 MHz mobile station antenna. Measurements were taken at distances of 0.5m from the closest windows in the first, second, third and fourth floors with Meter NBM-550 with an isotropic E-Field probe for 1hour at each floor. Power density ranged between $0 \mu\text{W/cm}^2 - 1.99 \mu\text{W/cm}^2$. Maximum power density was measured at 33

mins with the minimum at 7 mins. The average power density was $0.57 \mu\text{W}/\text{cm}^2$. Exposure levels were found to vary due to the presence of other objects (houses etc), fast fading and shadowing effects. (Bergqvist et al, 2001). (Amoako, Fletcher and Darko, 2009) also did a survey to measure and analyse the electromagnetic field strength levels emitted by antennae installed and operated by the Ghana Telecommunications Company. The results indicated that power density levels at public access points varied from as low as $0.01 \mu\text{Wm}^{-2}$ to as high as $10 \mu\text{Wm}^{-2}$ for 900 MHz. and $0.01 \mu\text{Wm}^{-2}$ to $100 \mu\text{Wm}^{-2}$ for 1800 MHz. These results were found to be in compliant with the International Commission on Non-ionizing Radiological Protection reference level.

In a research paper presented by (Szmigielski et al, 2000) about 3500-4000 career military service was considered as occupationally exposed to RF/MW. The population size was divided into five subgroups, according to type and level of exposure. Fig 2.14 shows the results. There were two main types of RF/MW-emitting devices which contributed to the exposure of military personnel - radio transmitting centres (RTC) (1-100 MHz) and radars (1-20 GHz). In relation to specific service and levels of exposure, the RTC was also divided into stationary (S-RTC operating at 1-30 MHz) and mobile (M-RTC using a wider range of frequencies 1 - 150 MHz). At the end of the research, it was stressed however that at least five subgroups of RF/MW-exposed military personnel can be differentiated as shown in Fig 2.14; for two of them the daily radiation dose (RD) was valued for $1.5-2 \text{ W}/\text{m}^2 \times \text{h}$, for other the two for about $5 \text{ W}/\text{m}^2 \times \text{h}$, while personnel of RF/MW repair workshops received a daily RD of about $8 \text{ W}/\text{m}^2 \times \text{h}$.

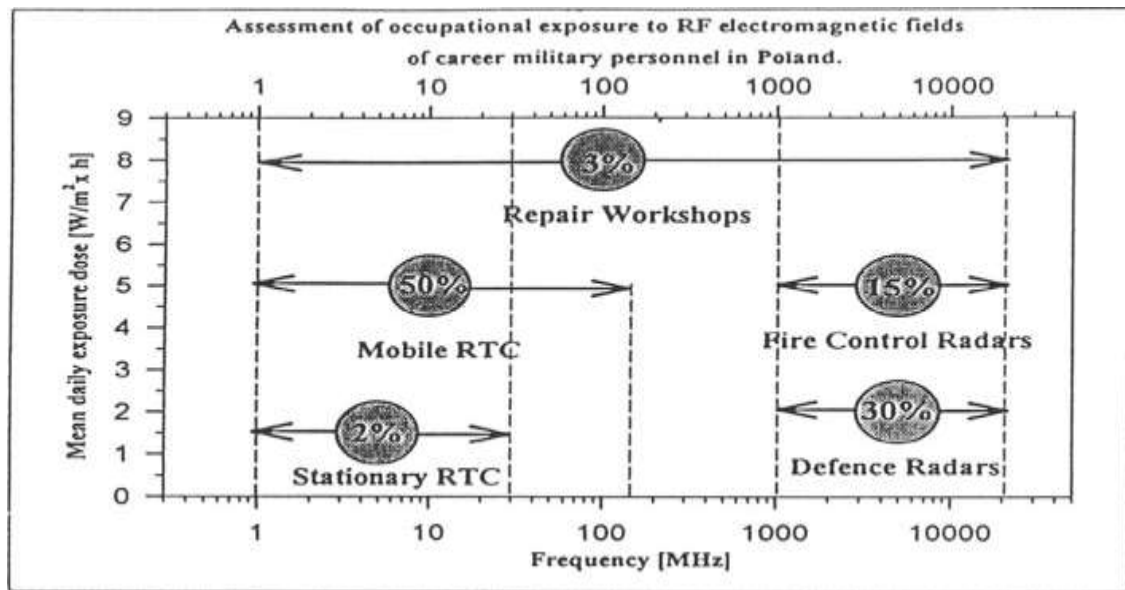


Fig 2.15: RF/MW exposure of military career personnel in Poland. Note two different levels of exposure for personnel servicing radio transmitting centers (RTC) and radars and high exposure levels for personnel of repair workshops.

Electronic Attack (EA) antennas were used by (Garrido, Ignatenko and Filipovic, 2014) to conduct research as to whether military personnel exposure inside military vehicles is not exceeding those limits set by the Federal Communication Commission (FCC). This was done through computational studies of the EM exposure on vehicle crew caused by ideal point sources and more realistic antennas used for EA and communications. Results were achieved with a method of moments and were validated with the finite element calculations. Finally, they gave estimated maximum accepted powers by the antennas that produce fields that fall under the FCC.

2.6.0 Calculation of Specific Absorption Rate (SAR)

According to (ITU-T, 2004), Specific Absorption Rate or SAR, is the rate at which RF energy is absorbed by a defined amount of mass of a biological body. It is a time derivative of the incremental energy (dE) absorbed by (i.e. dissipated in) an incremental

mass (dm). This incremental mass is contained within a volume element (dV) of a given density (ρ). This is indicated as

$$SAR(JKg^{-1}s^{-1}) = \frac{d}{dt} \left(\frac{dE}{dm} \right) = \frac{d}{dt} \left(\frac{dE}{\rho dV} \right) \dots \dots \dots 8$$

SAR can also be obtained with either of the equations below:

$$SAR = \frac{\sigma E^2}{\rho} \dots \dots \dots 9$$

$$SAR = c_h \frac{dT}{dt} \dots \dots \dots 10$$

$$SAR = \frac{J^2}{\rho \sigma} \dots \dots \dots 11$$

SAR is the specific absorption rate in watts per kilogram;

E is the r.m.s. value of the electric field strength in the tissue in volts per meter;

σ is the conductivity of the tissue in siemens per meter;

ρ is the density of the tissue in kilograms per cubic meter;

c_h is the heat capacity of the tissue in joules per kilogram and kelvin;

$\frac{dT}{dt}$ is the initial time derivative of temperature in the tissue per kelvin

J is the value of the induced current density in the body tissue in ampere per square meter.

2.6.1 Specific Absorption Rate empirical studies

Radio Frequency waves above 100 kHz produce heat in tissues and that a very high –level RF field may cause thermally related health effects (ICNIRP, 1998). ICNIRP used SAR as a primary dosimetric parameter for radio frequency energy absorbed by the human body. According to (ITU-T, 2004) the whole body –average SAR for occupational and public

exposures for the frequency range being used for the research are 0.4 and 0.08 W/Kg respectively. The SAR measurement procedure using an E-field probe comprising diode-loaded dipole with respect to a mobile phone for compliance testing, which is intended to be used at the side of a human head, was standardized by the International Electrotechnical Commission (IEC, 2005). A paper presented by (Onishi, Iyama and Kiminami, 2009) researched into faster Specific Absorption Rate measurement technique based on a previously proposed estimation method. The previous measurement method was timing consuming, but this new method reduced the SAR measurement time without sacrificing accuracy.

A study on specific absorption rate was also done in Bangladesh by (Fazlul,Hossain,Mollah & Akramuzzaman, 2013). In this study,17 radio operators of Bangladesh Radio were investigated. Calculations were done for specific absorption rate and consequent rise in temperature in human tissue. Maximum power density values for the Bangladesh operator was $1.27 \times 10^{-6} \text{ W/m}^2$ and the highest SAR value was about $\frac{1.6\text{W}}{\text{Kg}}$. The temperature rise in 6 minutes time because of the absorption of RF radiation from mobile operators was between 0.022 K -0.763 K. The local peak SAR levels of held radios inside the head usually differ depending on factors such as the source and characteristics of RF-EMF exposed to the operator or technician (Wiart et al, 2008). In most RF-EMF studies, calculation of SAR is presented as electric fields intensity and dose (Brouwer, 2010).

As indicated in the various literature reviewed, not much work has been done with the tactical expedient antennas propagation bands (HF, VHF, and UHF) in the Armed Forces. Most of the research works of power density and specific absorption rate calculations were done within the GSM (900MHz and 1800MHz) within and outside the country. This research was conducted within the HF and VHF of the RF bands to add relevant knowledge to the field of RF radiations especially the use of the military expedient antenna.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Introduction

This chapter describes the materials and methods used for the research work. Two different measurements (Field and Laboratory) were taken. The field measurements were done during operating peak periods of transmission of messages at Signal Training School, Burma Camp. Power densities were calculated using the data from the on-site measurements for base stations (Radio 1), whip (Radio 2) and vehicle-mounted (Radio 3) antennas. Laboratory measurements for the calculation of Specific Absorption Rate (SAR) were also done for (Radios 4) at the National Communication Authority. A numerical predictive model was developed to estimate the power density levels at varying distances, timings and positions of personnel (vehicle mount) using the antenna physical parameters.

3.2 Materials

The following materials were used for both field and laboratory study:

1. Anritsu Spectrum Analyser
2. Log Periodic Antenna
3. Garmin Oregon 200 GPS
4. Tactical radios with antennas
5. Phantom
6. Tissue Equivalent Liquid
7. Robot

3.2.1 Anritsu Spectrum Analyser

An Anritsu spectrum analyzer (Spectrum Master) for RF and Microwave Handheld Instruments with serial number 0940037 and a model number of MS2720T was used. It is frequency selective and measures the electric or magnetic field strength from one or more sources in a narrow frequency band. Anritsu Spectrum Master (Fig 3.1) displays the field strength (amplitude) versus frequency through the frequency range of interest. The spectrum master is sensitive to RF within the range of 9 kHz – 43 GHz. The spectrum master was connected via an RF (lead shield coaxial) cable to a log periodic antenna as indicated in Plate 3.1.



Fig 3.1 Anritsu Spectrum Analyser

3.2.2 Log Periodic Antenna

A Transformational Security log-periodic antenna (Fig 3.2) TS 8021 with serial number 00326 was used. The radiating element is sensitive and effective within the Frequency

Band of 3 MHz -3 GHz. The antenna cables used was a coax-cable which was matched to the receiver input impedance as well as to the antenna load impedance of 50 Ω .



Fig 3.2 Log Periodic Antenna

3.2.4 Garmin Oregon 200 GPS

The Oregon 200 GPS (Fig 3.3) manufactured by Garmin Company was used in recording the coordinates of locations of the HF radiating antennas and the measurement points (substations). In

addition, an in-built Anritsu GPS was also used to log the data with respect to measurement position on the spectrum data.



Fig 3.3 Garmin Oregon 200 GPS

3.2.4 The Phantom

A phantom (Fig 3.4) has been produced based upon the dimensions of a large adult male head in order to achieve a measure of SAR that will include all types of people. This phantom has been constructed with compressed thin ears to simulate users with small ears. In addition – right and left model heads are used to ensure that the different exposure areas caused by the asymmetric location of the antenna in many phones are being measured.



Fig 3.4: Phantom

3.2.5 The Tissue Equivalent Liquid

The Tissue Equivalent Liquid is a special liquid that correlates with the dielectric properties of human head tissue or body. The dielectric properties of 'head tissue' have been calculated taking into account the properties of human brain tissue and the matching effects of the outer tissue layers of the head (e.g., skin and skull) to provide a conservative overestimate of the values. Different liquids are used to test different frequencies.

3.2.6 The Robot

The robot consists of a mechanical arm and a special probe which is used to derive the actual SAR measurements. The measurements are carried out by establishing a reference point in the phantom and then scanning a specified area in and around the phantom while the phone is operating at its maximum certified power level.



Fig 3.5 Robot



Plate 3.1 Measurement instrumentation

3.3 Methodology

The methodology of this research was done by taking field measurements (electric field strengths) of the various radio antennas and laboratory measurement of the specific absorption rate of a hand held radio with the assumption that the antennas of the radios are emitting electromagnetic radiation continuously.

3.4 Sampling of the field measurements for power densities

Four (4) field radiating antennas of HF radios used by the Ghana Armed Forces were selected according to their proximity to buildings, antenna parameters; mounting height and effective isotropic radiating power. The information on the technical parameters of the antennas was provided by the technicians of the Signal Training School (STS). The antenna was selected based on their employment. Fig 3.2 shows the GPS location where spot measurements were taken during field sampling.

3.4.1 Determination and Documentation of the Test point(s)

Measurement points within the vicinity of each EM radiating antenna were determined based on random sampling and population distribution within the Barracks. Measurement points (substations) were chosen to represent the highest levels of exposure to which a person might be exposed considering the positions of the antennas. The measurements were done for the base stations (Fig 3.2), manpack and vehicle-mounted radios. A constant frequency of 5.52 MHz was kept throughout the experimentation. Measurement sites were selected in such a way that there were few reflecting objects and as few overhead conductors (power and telephone lines, antennas, buildings with metal roofs or gutters) as possible. These locations were noted by a quick check using measuring equipment. Each measurement test point was recorded 1.5 m above ground level.



Fig. 3.6 Google earth of coordinates and test points of Signal Training School radiating antenna.

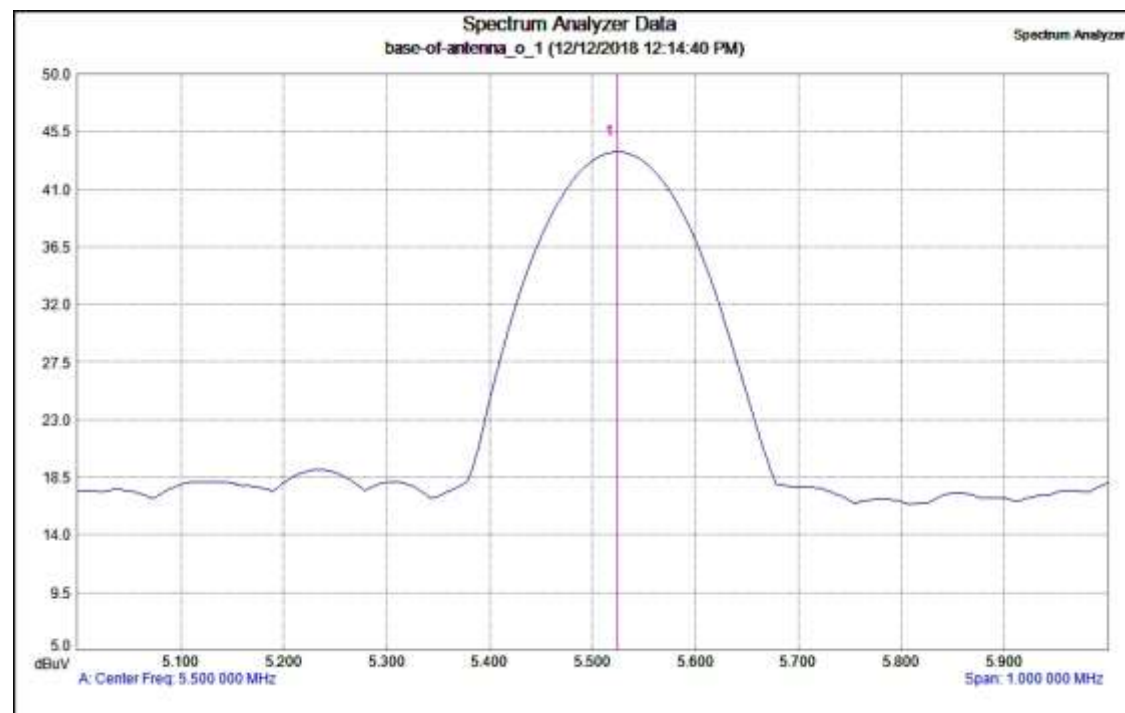
3.4.2 Measurement of the electric field

Four Scenarios were created to depict real-time deployment of troops in the field. These were static Units in the defense (base station), troops on foot patrols (Manpack), troops on mounted patrols (mounted antennas) and the radio operator's location during transmission. The Log-periodic antenna in all these scenarios was held at various directions until the highest peak was noted on the spectrum master (Sweep spatial averaging method). The

transmitting signal was recorded over two (2) minutes period as a DAT file on the Spectrum master and later downloaded unto a laptop for analysis.

3.4.2.1 Measurement of the Electric Field Around a Base Station

The first two scenarios were created with a static military position with base station radio. An inverted V antenna with a mast of height 50 m was mounted, the electric field strength measurements were taken at the base of the antenna and at various distances from the base of the antenna. Measurements were also taken (scenario 2) at the entry, exit and any other points in the operations room. The transmitting signals were recorded as DAT files on the Spectrum Master which were later converted to jpeg files.



Source: Fieldwork 2018

Fig 3.7 Spectrum location base station radio antenna radiating at 5.52 MHz

3.4.2.3 Measurement of the electric field around antennas on manpack radios

Scenario 3 was created by measuring the electric fields around an antenna of a manpack HF radio. The radio was transmitting with the full length of its antenna. Measurements were also taken with the Spectrum Master at various distances. The transmitting signals were recorded as DAT files on the Spectrum Master which were later converted to jpeg files.



Source: Fieldwork 2018

Plate 3.2 Manpack radio in use by a soldier

3.4.2.4 Measurement of the electric field around antennas on vehicle-mounted radios

Scenario 4 was also created by measuring electric field around an antenna of mounted radios of a military vehicle. The antenna was mounted in front of the vehicle. Measurements were also taken with the Spectrum Master at the driver's seat, commander's

seat and escort's seat. The transmitting signals were recorded as DAT files on the Spectrum Master which were later converted to jpeg files.



Source: Fieldwork 2018

Plate 3.3 A typical radiating antenna on a military vehicle

3.4.3 Determination of field strength and power density

The various maximum peaks for each subband during transmission were marked and plotted using a spectrum analysis package installed on a personal computer. The frequency was set from 5.0 MHz as the start frequency and 6.0 MHz as stop frequency. This is indicated in Fig 3.4 and results tabulated in dB μ V/m. The radiofrequency (RF) cable and antenna factor losses were corrected in the measured field strength (dB μ V/m)

by selecting the appropriate antenna and converting to V/m from the spectrum analyzer library according to the following equation (ECC, 2004):

$$E_{B,P} \text{ dB}\mu\left(\frac{V}{m}\right) = K\left(\frac{dB}{m}\right) + V_m(\text{dB}\mu V) + L(\text{dB}) \dots\dots\dots 12$$

where $E_{B,P} \text{ dB}\mu\left(\frac{V}{m}\right)$ is the corrected electric field strength for cable and

antenna losses taking polarization into consideration

$K\left(\frac{dB}{m}\right)$ is the antenna correction factor,

$V_m(\text{dB}\mu V)$ is the measured electric field intensity without cable and antenna correction

$L(\text{dB})$ is the cable correction factor.

The corrected field strength in $\text{dB}\mu\left(\frac{V}{m}\right)$ was then converted into $\left(\frac{V}{m}\right)$ according to the following equation (ECC, 2004):

$$E\left(\frac{V}{m}\right) = 10^{\left\{\frac{E(\text{dB}\mu V/m) - 120}{20}\right\}} \dots\dots\dots 13$$

The average electric field strength E_{avg} for the various scenarios were estimated as resultant of the two polarized electric field strength values at the operating frequency and summing (using the principles of the root of the sum of the squares (RSS)) within the entire operating bandwidth

$$E_{avg} = \sqrt{\left(\sum_{n=ni}^P E_n^2\right)} \dots\dots\dots 14$$

where $n = n_1 + n_2 + n_3 + \dots + P$ is the subunits (measurement points)

3.4.4 Uncertainty Estimation.

The estimation of uncertainty, as a result of the measurement, was evaluated for the electric field measurements taking into account each of the various sources of uncertainty in the measurements. The standard uncertainty $u_{(xi)}$ and the sensitivity coefficient c_i were evaluated for the estimate xi of each quantity. ($c_i = 1$). The combined standard uncertainty $U_c(E_{avg})$ of the estimate E of the measured value is calculated as a weighted root sum square (r.s.s.):

$$u_c(E_{avg}) = \sqrt{\sum_{i=1}^n (c_i * u_{(xi)})^2} \dots \dots \dots 15$$

The uncertainty associated with the electric field measurement is shown in the Appendix (Table D1). Using the uncertainty values derived from Table A1-C1 and according to Equations (3.4-3.5), the expanded uncertainty was estimated for each scenario. The power density (S) and the associated uncertainty $u(S)$ were estimated assuming far field conditions using the following equations (ECC, 2004):

$$S = \frac{E_{avg}^2}{377} \dots \dots \dots 16$$

$$u(S) = 1.96u_c(E_{avg}^2) \dots \dots \dots 17$$

The power density for the antenna was recorded as $S \pm u(S)$ with a unit of W/m^2 . This recorded uncertainty is based on a standard uncertainty multiplied by the coverage factor of 1.96 which yields a 95 % level of confidence for the near-normal distribution typical

of most measurement results. The uncertainty analysis is based on ECC methodology (ECC, 2004)

3.4.5 Exposure Quotient

The ratio of $\frac{E_{meas}^2}{E_{ICNIRP}^2}$ (measured to reference electric field) was calculated to obtain the compliance level for each scenario where E_{meas} is the value determined from equation 14 and E_{ICNIRP} is the value of the existing maximum permissible emission level set by ICNIRP.

3.5 Measurement for Specific Absorption Rate (SAR)

The measurements which were done in the SAR laboratory were taken in line with the International Electrotechnical Commission Guidelines (IEC,2005). With these guidelines, the dielectric properties of the liquid used were confirmed to check whether it was still within approved standards. The ambient noise (RF Noise) was also checked to achieve a level of $< 12 \text{ mW/Kg}$. After that dipole evaluation was also done to make sure that the final result will meet the standards. This was achieved by taking a full SAR (1g and 10g SAR values) measurement of a dipole in a frequency band, making sure the final SAR value would comply with standards. Finally, the actual test was done with two (2) of the Radio 4 operating at the same frequency. One was connected to a device under test (DUT) holder (receiver) with the other at a distant (transmitter) for the SAR measurement to be done. The setup for the test is as shown below. The results were analyzed using the OpenSAR software.

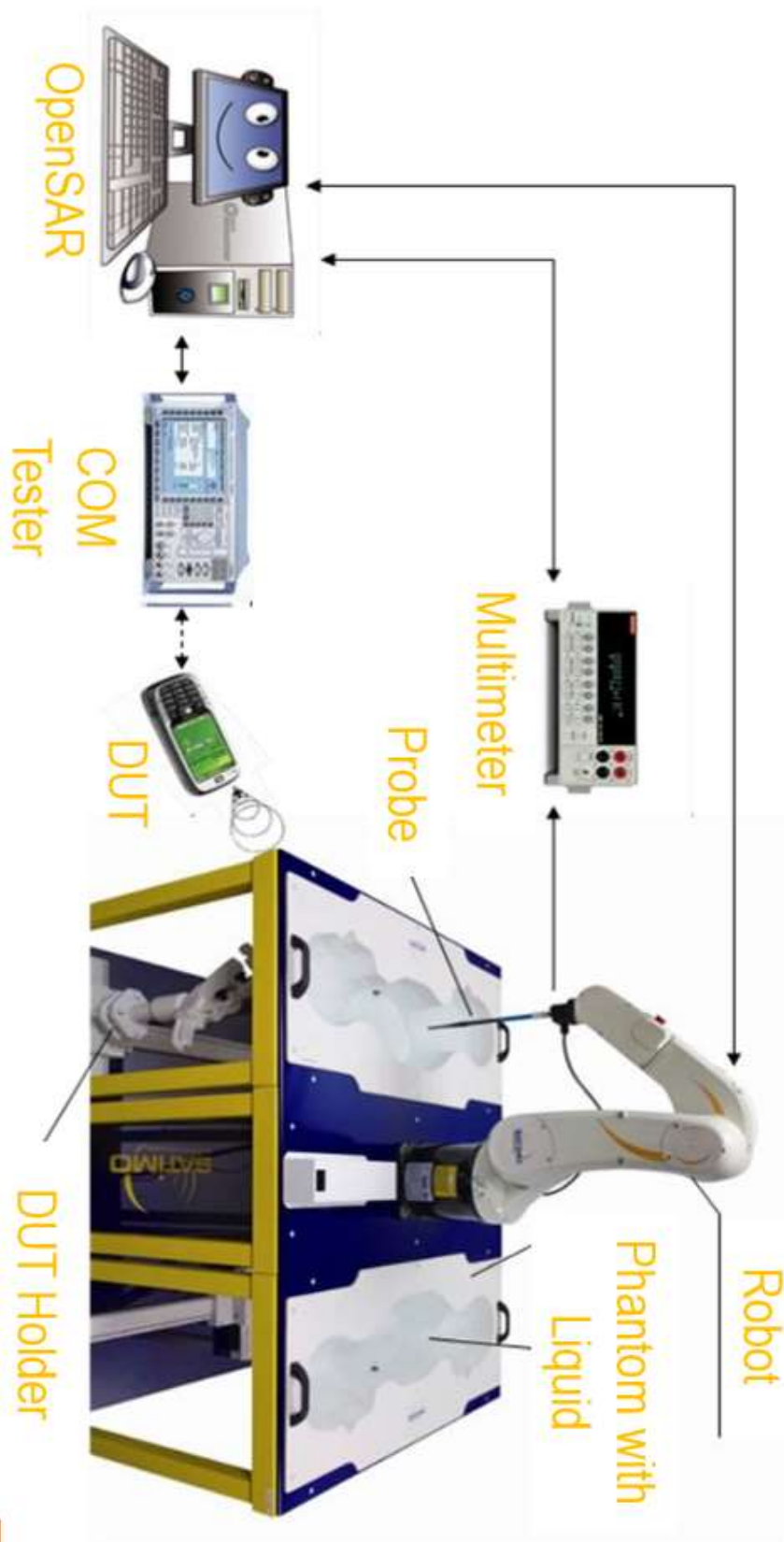


Fig 3.8 The test configuration of a DUT SAR evaluation.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Introduction

This chapter seeks to present the results obtained, the discussions for all measurements and then compare with standard values of ICNIRP. The research was performed using four real scenarios of employment with tactical antennas with an operating frequency of 5.52 MHz. The tactical antennas were base stations, manpack, vehicle mount (mobile) and operator's exposure at the operations room. The electric field strengths at various distances were measured and the corresponding power densities (W) also calculated. The exposure quotients for each of the scenarios are also discussed. Additionally, the results obtained from the Specific Absorption Rate of the handheld radio was also discussed. The results from this research work have been compared to international standards.

4.2 Radiating antenna used as a Base Station

The electric field strengths of the radiating base station antenna were randomly measured within the far-field of the antenna. From the results in Fig 4.1, there is a sharp decrease in the electric field strength from 0.02 V/m to 7.93×10^{-5} V/m. The power density levels also decreased by the square of the radial distance (inverse square law) as measurements were made at the various test points by increasing radial distances from 19.00 m to 271.00 m away from the tactical radiating antenna. There was also no significant change in strength except for some few fluctuations in strength from 50.0 m to 150.0 m. These observations could be attributed to several factors such as obstruction by structures within the line of sight of measurement, noise from moving objects such as vehicles, motorcycles, etc., and elevation of the land area around the tactical radiating antenna with respect to radial distance away from the antenna. There was also no significant change in strength from

150.0 m to 271.0 m. This is because the strength is weaker at those distances indicating that bodies within those distances might not experience any significant biological effect.

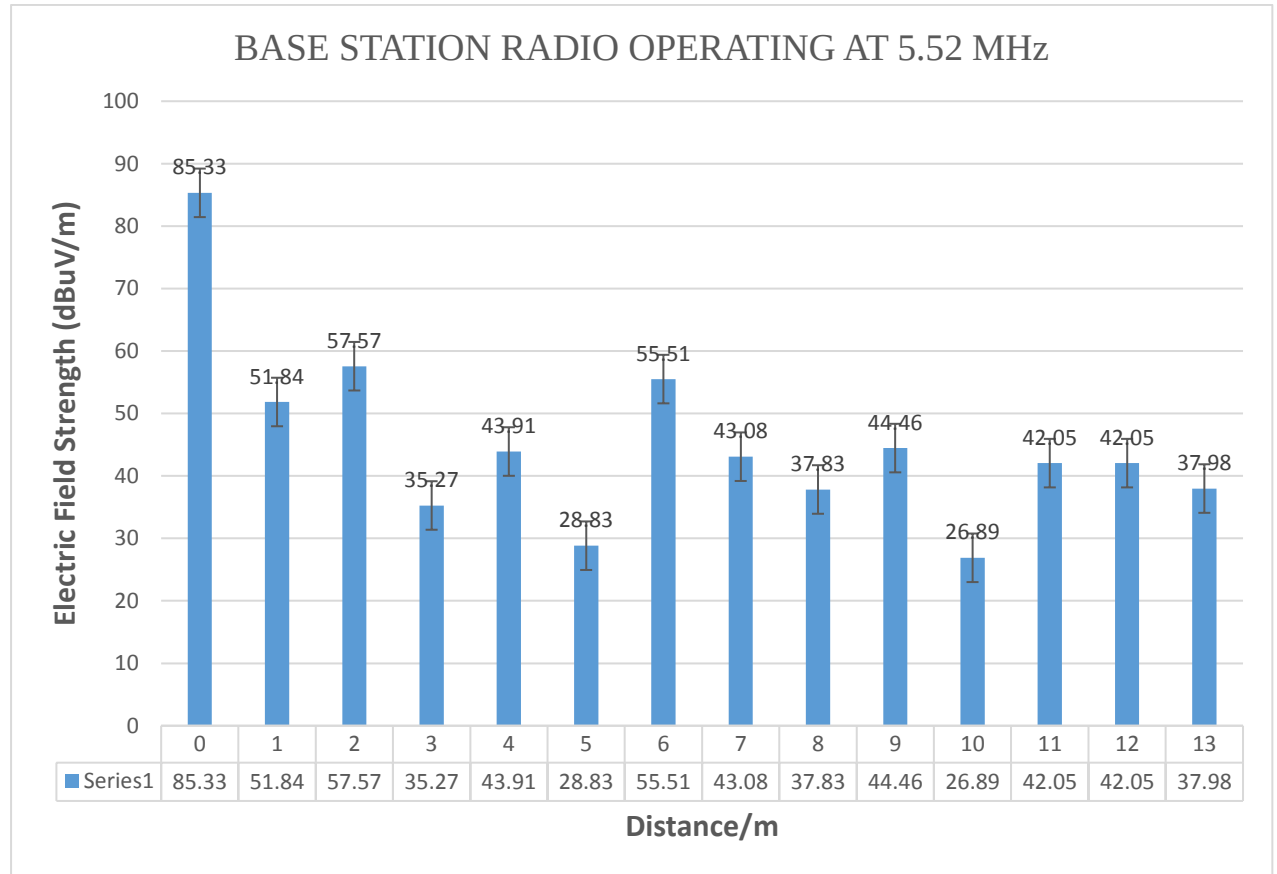


Fig. 4.1 Plot of Electric Field Strength against Distance (Base Station).

4.3 Radiating antenna from a Manpack Radio

From Fig 4.1 the highest electric field strength of 0.36 V/m was measured at the surface of the manpack within a few centimetres and the least of $7.83 \times 10^{-5} \text{ V/m}$ at 62.0 m. Like the first scenario, there was also a general decrease in strength at various distances away from the radiating antenna. This confirms the theory of inverse square law. It was observed that there was a sharp decrease from the surface to 10.0 m but no significant changes in the rest of the measurements.

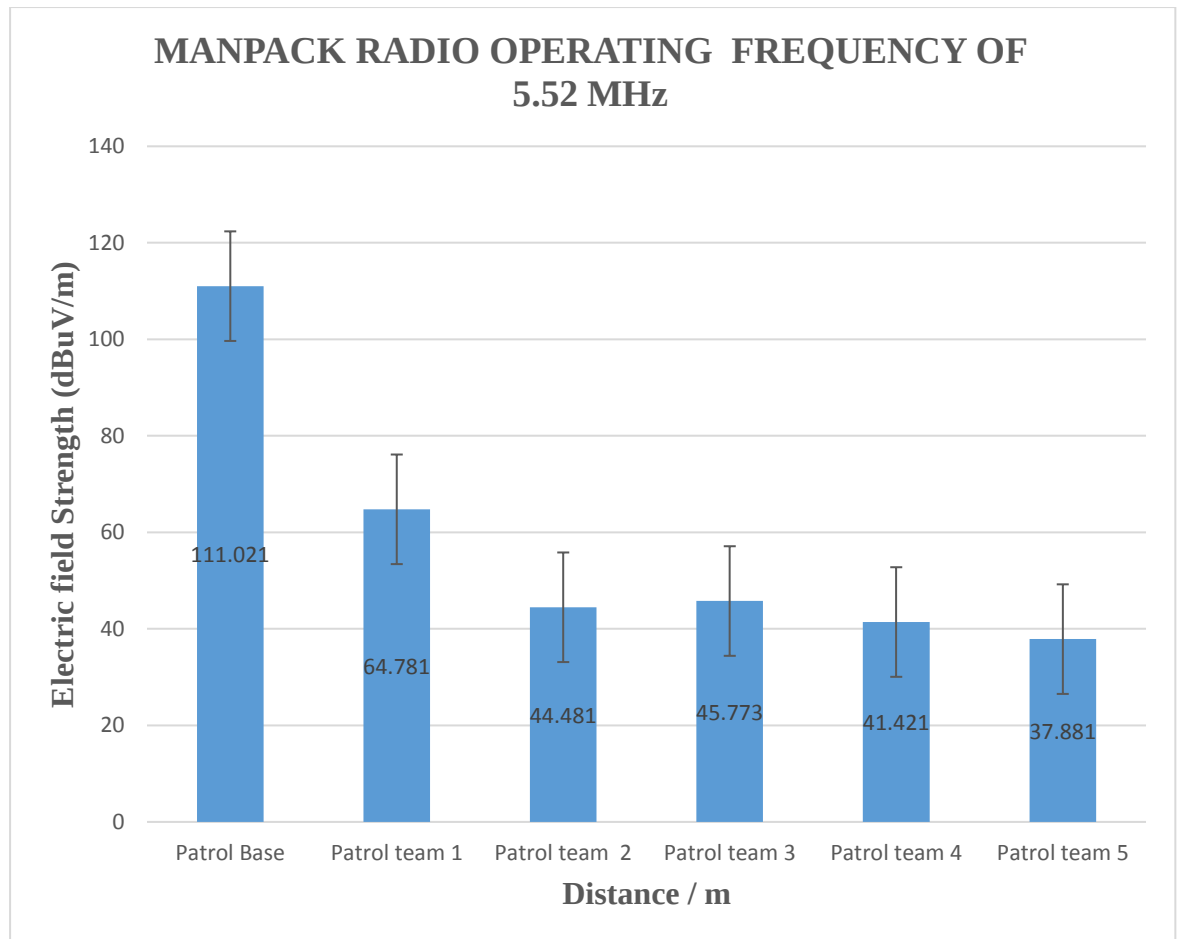


Fig. 4.2 Plot of Electric Field Strength against Distance (Manpack)

4.4 Radiating antenna effect in the Operations Room

The results from Fig 4.3 show the electric field strength at four different places in the operations room where measurement was taken. These were the operator's seat, any location in the room, entry and exit points. From observation, the entry and exit points had the lowest measured electric field strength of $9.44 \times 10^{-4} \text{V/m}$. The operations room had similar value for entry and exit because most operations room have the same entry and exit points. The operator's seat had the highest value of 0.04 V/m. This may be attributed to the emissions from other radios available in the room also operating on the same frequency closer to the operator. These include other HF or VHF radios. Any other location in the room is usually occupied by a second operator.

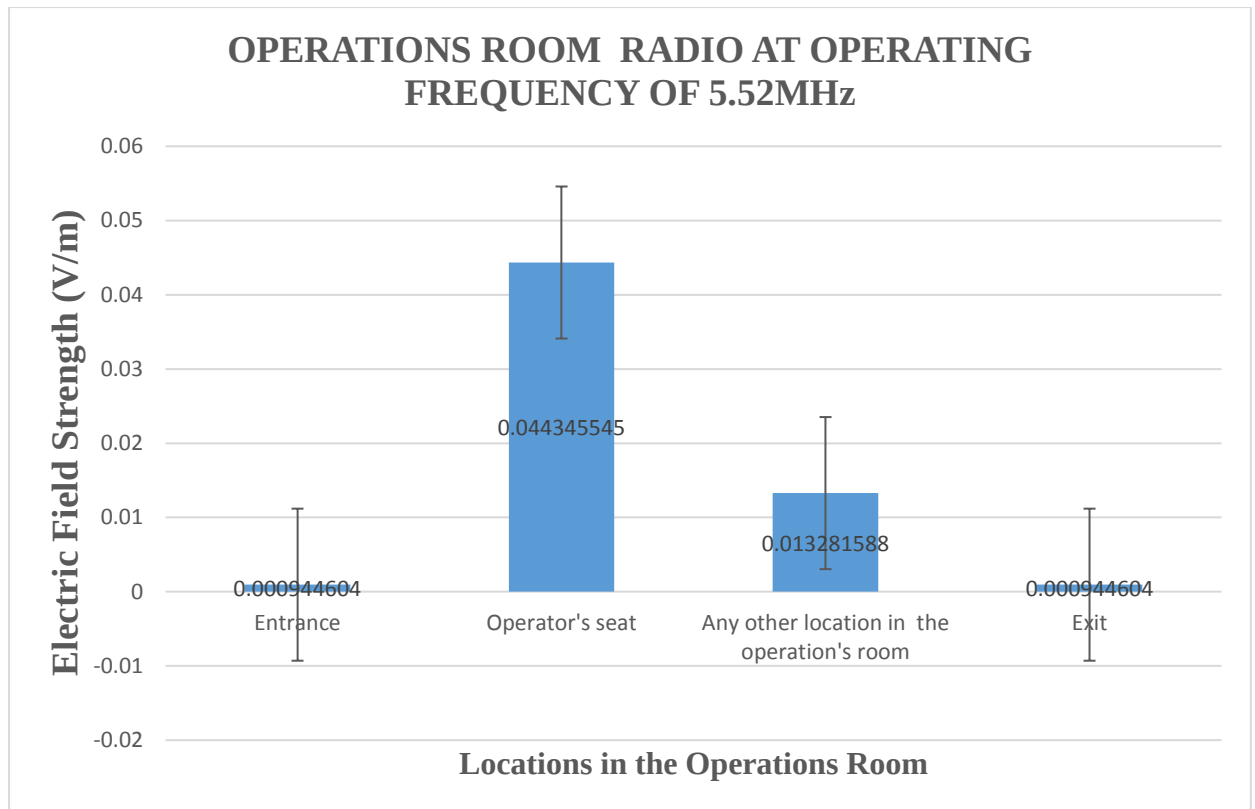


Fig. 4.3 Plot of Electric Field Strength against locations in Operations Room.

4.5 Radiating antenna of a Vehicle-Mounted Antenna

Three seating places are usually occupied by passengers in military vehicles. These are driver's seat, the escort/bodyguard and the commander at the rear behind the escort. The results from Fig 4.4 show that although the driver and the escort sit on the front seat, the escort recorded relatively high electric field strength (0.04 V/m). This can be attributed to electronic emissions from other radios installed in the vehicle operating on the same frequency. The commander's seat had the least electric field strength recorded. This also can be attributed to the position of the seat (behind the escort). In this case, the escort serves as an 'unintentional' RF shield.

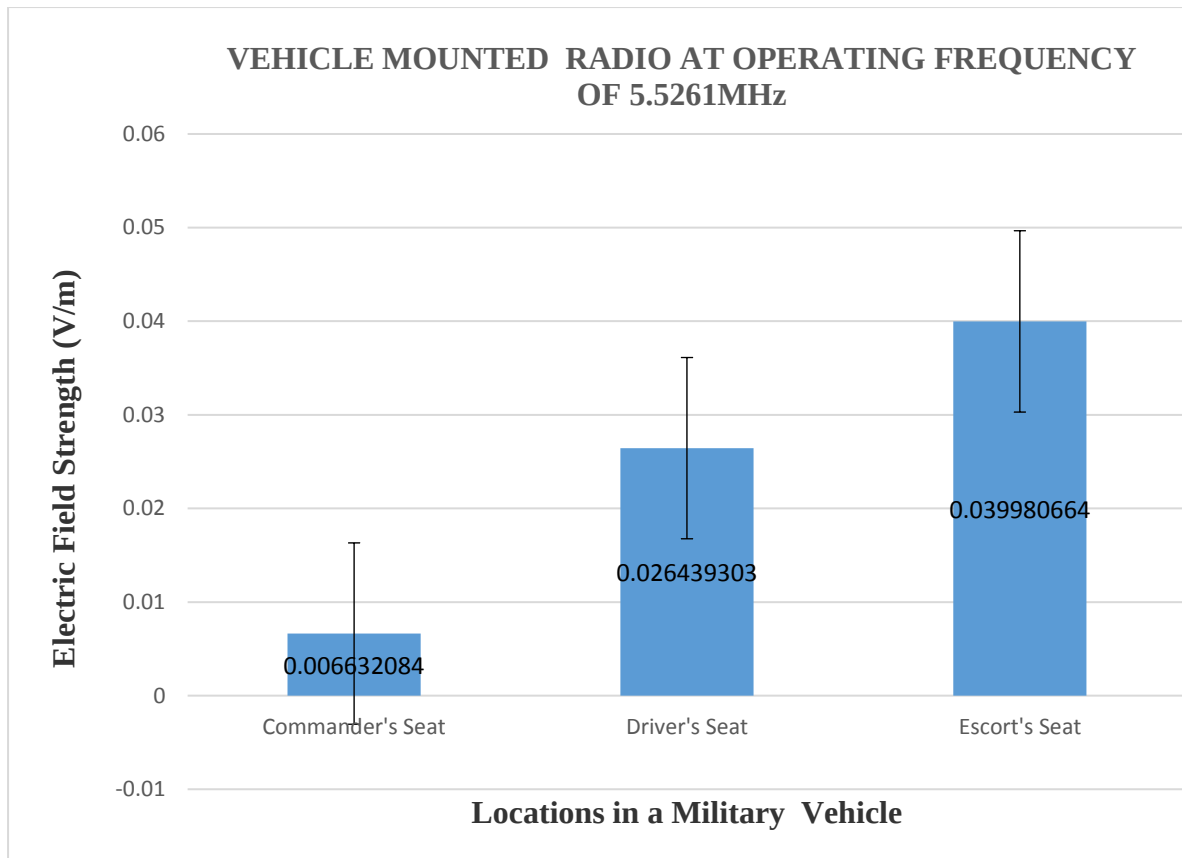


Fig. 4.4 Plot of Electric Field Strength against Seating Positions in Military Vehicle.

4.6 Exposure Quotient

The exposure quotient is the summation of the ratio of power density levels determined in this research study to the Maximum Permissible Emission levels set by the ICNIRP. Exposure quotient is used to check compliance with national and international limits. For compliance, the maximum exposure quotient values determined should not be more than 1.

The recommended ICNIRP reference electric field strength values for occupational ($610/f$) and general public exposure $87/f^{1/2}$ were used. This was calculated for all the four scenarios.

The maximum values recorded for this research work for the general public exposure was 7.14×10^{-2} and 3.22×10^{-9} for occupational exposure from manpack radio. The exposure

quotient at a base station should not exceed 1 for complying with maximum exposure limit recommended by ICNIRP. In this research, the values obtained were less than unity (1) hence, were within the international acceptable limits. The exposure quotient values obtained in this study were relatively low due to the fact that the measurements were carried out in the far field regions of the various field radiating antennas. Exposure quotient was calculated for each scenario as shown in Table 4.1 below

Table 4.1. Estimated exposure quotient from measured electric field strength

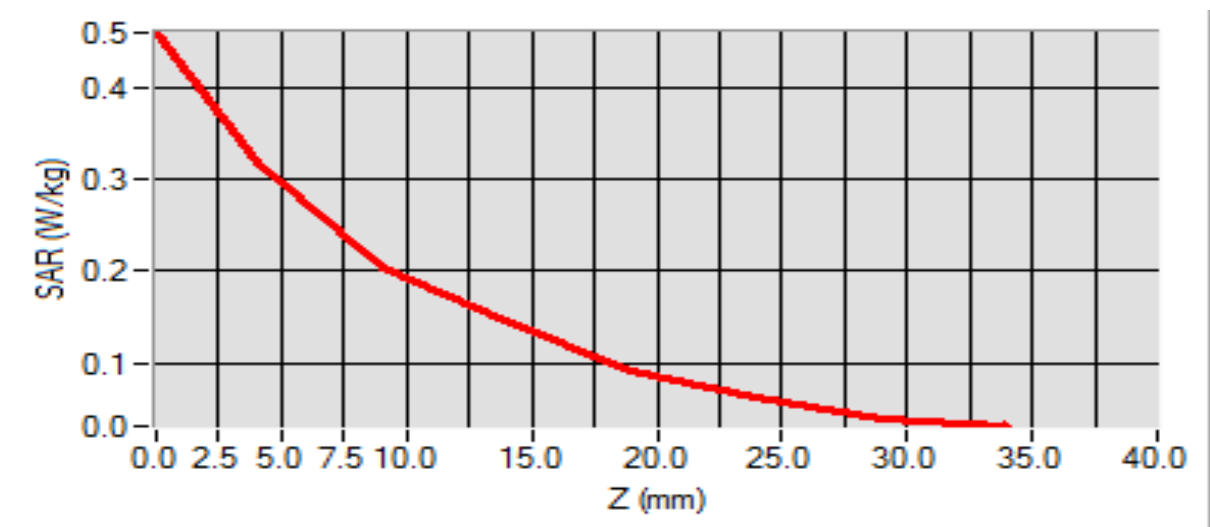
Scenario	Occupational Exposure Quotient	General public Exposure
Base station	1.67×10^{-10}	3.22×10^{-9}
Manpack	3.22×10^{-9}	7.14×10^{-2}
Vehicle-mounted	2.67×10^{-14}	9.71×10^{-3}

4.7 Specific Absorption Rate Measurement of Radio_4HH

This part of the research work was carried out at the NCA SAR laboratory on the handheld radios used in the Armed Forces. Equation (8-11) shows the direct proportionality of SAR to conductivity in a radiated tissue and inversely proportional to the physical density of that tissue. The relevant data describing the physical properties of the human tissue (liquid equivalent tissue) and the electrode materials (density, specific heat, and conductivity) were determined during the calibration as shown in Appendix H (Table H3). Again since the conductivity and density for particular tissue are constant with a definite frequency (700 M Hz), SAR is inversely proportional to the square of the distance from the source to the tissue indicated on the graph. From the results obtained in Table 4.2, the SAR 10 g (W/Kg) is 0.19 and SAR 1g (W/Kg) is 0.31 with a peak SAR of 0.46 at the surface of the tissue.

Table 4.2: SAR measurement of Radio_4HH

Z (mm)	0.00	4.00	9.00	14.00	19.00	24.00	29.00
SAR (W/Kg)	0.4612	0.3197	0.2044	0.1460	0.0912	0.0632	0.0380

**Fig. 4.5 Plot of SAR (W/Kg) against depth, Z (mm) for Radio _4HH**

4.8 Comparison with International Standards

The results of electric field levels of the field measurements and the SAR measurement in this study have been compared to the ICNIRP limits to check for compliance. According to (ICNIRP, 1998), the reference electric field strength for occupational and general public exposure is $(610/f)$ and $87/f^{1/2}$ for frequencies between 1-10 MHz. From the four scenarios in this research, the highest measured value of electric field occurred with the manpack radio at the base of the radiating antenna at $3.56 \times 10^{-1} V/m$ with a corresponding power density of $3.36 \times 10^{-4} W/m^2$. The results obtained depicts that the measured values

for the electric field with their corresponding power density levels are far below the reference levels set for both general public and occupational exposure.

The localized SAR (head and trunk) for occupational exposure and public exposure are 10 W/kg and 2 W/kg respectively. From the SAR measurement, 0.19 W/Kg was obtained for SAR 10g (W/Kg) and 0.31 W/Kg was also obtained for SAR 1g (W/Kg). These SAR values obtained for Radio_4HH is also far below the reference levels set for both general public and occupational exposures.

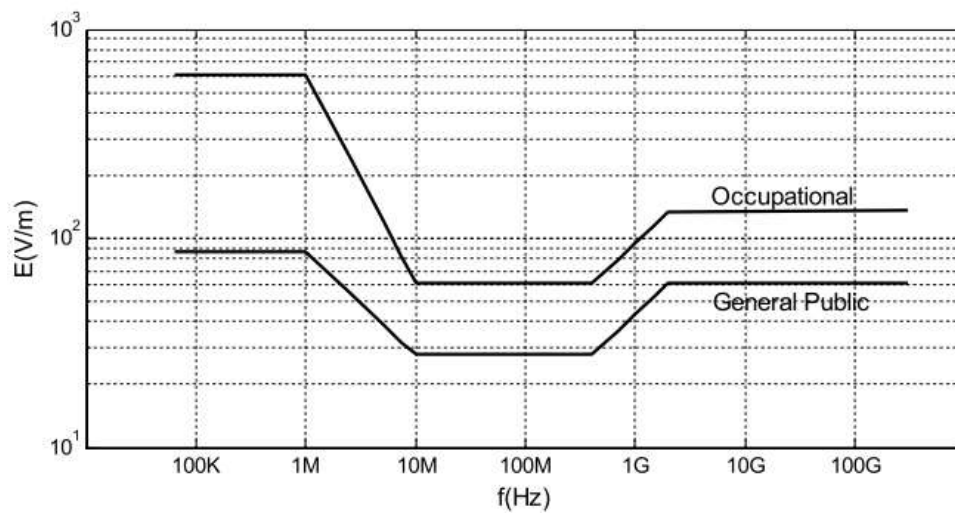


Fig 4.6 Plot of Electric Field Strength against Frequency showing compliance for Occupational and General public exposure (ICNIRP, 1998)

Table 4.3 Maximum Measured Safety Distance for Workers

	HF125W(5MHz)	VHF 50W	UHF 50W(220MHz)
ICNIRP Limits	122 V/m	61 V/m	61 V/m
Safe Distance	3m	2m	1.6m

4.8 Comparison of results with other researched works.

The obtained results from this measurement was compared to work done by (Šarolic and Modlic, 2007), (Sobiech et al, 2017) and (Alcaras and Frere, 2017) who conducted a research of electric field strength of military HF radio antennas in different countries under varying experimental conditions. (Sobiech et al, 2017) evaluated the exposure of Polish military personnel to electromagnetic fields. The electric field strength emitted by Portable radios was between 20–80 V/m close to a human head. The manpack radio operator's exposure was 60–120 V/m. Vehicle mounted antennas with high frequency/very high frequency (HF/VHF) band radios was 7-30V/m.

Similar work was also done by (Alcaras and Frere, 2017) on military radio communication devices to justify that their HF, VHF and UHF radio are compliant with ICNIRP standards in terms of hazardous electromagnetic radiation. A 125 W HF, 50 W VHF and 50 W UHF radios operating between 1 and 30 MHz, 30 and 88 MHz and 220 and 512 MHz were used. At a distance of 1m, the maximum electric field level measured from a typical military vehicle for all the three bands were 1200V/m, 200V/m and 100V/m respectively. These results can be with maximum measured safety distance for workers by ICNIRP for three the bands.

(Šarolic and Modlic, 2007) also analyzed the electromagnetic (EM) radiofrequency (RF) radiation hazards onboard a ship arising from shipboard radio communication and its effects on personnel and equipment. The HF electromagnetic radiation source was a single side band (SSB) radio transmitter which is similar to the radios used for this research. This analysis and measurements were done at the frequency of 10 MHz. The results obtained for the Permissible Exposure Limit for controlled areas was $10W/m^2$ and uncontrolled areas was $2W/m^2$.

All the results above from the three research works compared to that of this work indicate compliance, as they are below the ICNIRP, recommended levels.

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CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

This chapter comprise the conclusion and recommendations made for further studies

5.1 Conclusion

The radiofrequency levels of some military field radiating antennas were studied based on their various employments. These were base station radiating antennas, manpack, vehicle-mounted antennas and handheld radios. The studies for the field measurements were done by creating a real-time scenario with radiating antennas of the various radios. The electric field strength around the field antennas and their corresponding power densities were measured. Also, the specific absorption rate of the of 4HH handheld radios at the NCA laboratory. The RF levels were estimated by taking measurements randomly at distances from the radiating antennas with the Anritsu spectrum master, log periodic antenna and a GPS. The assumption made during the measurements which might affect the accuracy of the graphs. However, the real-time measured data indicates that the model is a good estimation of the upper bounds of the equivalent power density levels occurring at the various test points near a field radiating antenna. The highest measured power density level for the base station, manpack and vehicle-mounted radiating antennas were, $9.05 \times 10^{-7} \text{ W/m}^{-2}$, $3.359 \times 10^{-4} \text{ W/m}^{-2}$, and $4.23 \times 10^{-6} \text{ W/m}^{-2}$ respectively. The general public and occupational exposure quotients for base station radiating antenna were 3.22×10^{-9} and 1.676×10^{-10} , manpack were 7.14×10^{-2} and 3.22×10^{-9} and vehicle mounted were 9.71×10^{-3} and 2.67×10^{-14} .

Measurement of the SAR level of a handheld radio in real-time transmission was taken at the laboratory of NCA. A continuous-wave was transmitted through the liquid-equivalent tissue and was detected by a probe. The SAR value of handheld radio was estimated to be

SAR 10g (W/Kg) is 0.19 and SAR 1g (W/Kg) is 0.31 with a peak SAR of 0.46 at the surface of the tissue. Although inevitable factors such as other military radio antennas operating at the same or close to the operating frequency had an impact on the measurements, the measured values for both the field and laboratory measurements were in conformity with the reference levels set by the International Commission on Non-Ionizing Radiation Protection (ICNIRP).

5.2 Recommendations

The following recommendations have been derived and are being presented to the appropriate institution from this research work.

5.2.1 Recommendation to Directorate of Communication

1. The Directorate in charge of signal communication in the Army should set up a cell responsible for safe and secure use of RF radiating sources headed by a radiation protection officer (RPO). Military radio contractors may consider design measures aimed at lowering electric field levels (exposure) while maintaining safe, secure and effective transmission of RF radiations.
2. The Directorate should ensure that military radio contractors have international (ICNIRP, FCC, IEEE) or local RF compliance certificate from NCA as one of the major requirements before procurement processes begins.

5.2.2 Recommendation to Occupationally Exposed Workers (Radio Operators and Technicians)

Occupationally exposed workers can reduce their exposure to electric fields by observing the following principles;

1. Radio Operators and Technicians should have adequate knowledge about the antenna and the effects of RF radiation exposure.
2. There should not be transmission in progress during maintenance work on the antenna.
3. Radio Operators and Technicians should adhere strictly to the safety instructions provided by the manufacturer.
4. Operations Room should not be within 5 m radius of the base station antenna.
5. Radio Operators should not use other devices radiating at the same frequency as the operating antenna whiles transmission is in progress.
6. During off-peak hours, operators should not be in the operations room whiles the radios are on.

5.2.3 Recommendation to the General Public (Troops)

Troops should take RF education seriously and adhere to the safety regulations.

5.2.4 Recommendation for Further Studies

The following recommendations are being made for future studies:

1. Research work should be carried out on new military radios that are purchased to check their RF compliance levels.
2. Research work should be done on all major Operations Rooms of Units.
3. Research work should be extended to the Naval Ships and Military Operations Rooms

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APPENDICES

APPENDIX A: REAL TIME CALCULATIONS OF VARIOUS EMPLOYMENTS OF THE FIELD ANTENNAS

A1. Real time Measurement of the base station antenna

For the substation 1 with 19m from base station antenna, the field strength in dB μ V/m across 50 Ω was measured as 85.33 dB μ V/m. The field strength in dB μ V/m was converted to the standardize electric field strength in units of V/m using equation 3.2

$$E\left(\frac{V}{m}\right) = 10^{\left\{\frac{E(dB\mu V/m)-120}{20}\right\}}$$

$$E\left(\frac{V}{m}\right) = 10^{\left\{\frac{85.33(dB\mu V/m)-120}{20}\right\}}$$

$$E\left(\frac{V}{m}\right) = 1.847 * 10^{-2} V/m$$

The power density of substation 1 in units of W/m² was then calculated using the equation below:

$$S(W/m^2) = \frac{E^2\left(\frac{V}{m}\right)}{377}$$

$$S(W/m^2) = \frac{(1.847 * 10^{-2})^2}{377}$$

$$S(W/m^2) = 9.050 * 10^{-7} W/m^2$$

The results of the power density levels at the various substation antennas are shown in Table C1.

The power density of the base station transmitting antenna is calculated using the equation below:

$$S = \frac{E_{avg}^2}{377} \dots \dots \dots (3.6)$$

$$S = \frac{3.42395 \times 10^{-4}}{377}$$

$$S = 9.082 \times 10^{-7} W/m^2$$

Uncertainty Estimation

The combined standard uncertainty $u_c(E_{avg})$ estimation for the base station antenna was calculated with the equation below:

$$u_c(E_{avg}) = \sqrt{\sum_{i=1}^n (c_i * u_{(xi)})^2}$$

Where the sensitivity coefficient of the type –B uncertainty, $C_i = 1$ (xi) is the uncertainty contributor at frequency i and $u_{(xi)}$ is the standard uncertainty due to the contributor(xi) at the same frequency (Table D1)

$$\text{Let } \sum_{i=1}^n (c_i * u_{(xi)})^2 = \alpha$$

$$\alpha = (1 \times 2.96)^2 + (1 \times 10)^2 + (1 \times 2.58)^2 + (1 \times 2.98)^2 + (1 \times 0.84)^2 \\ + (1 \times 0.05)^2$$

$$= 25.0165$$

$$u_c(E_{avg}) = \sqrt{\alpha}$$

$$u_c(E_{avg}) = \sqrt{25.0165}$$

$$u_c(E_{avg}) = 5.00\%$$

The expanded uncertainty is also expressed as:

$$u(S) = 1.96u_c(E_{avg})$$

$$u(S) = 1.96 \times 5.00\%$$

$$u(S) = 9.80\%$$

The power density of the base station antenna transmitting at a frequency of 5.5261MHz is $9.082 \times 10^{-7} \pm 8.900 \times 10^{-8} \text{W/m}^2$

A2. Real-time Measurement of the Manpack Radio Antenna (Radio 2)

For the measurement point 1 with a distance of 10m from manpack radio antenna, the field strength in dB μ V/m across 50 Ω was measured as 111.021dB μ V/m. The field strength in dB μ V/m was converted to the standardize electric field strength in units of V/m using the equation below:

$$E \left(\frac{V}{m} \right) = 10^{\left\{ \frac{E(\text{dB}\mu\text{V}/\text{m}) - 120}{20} \right\}}$$

$$E \left(\frac{V}{m} \right) = 10^{\left\{ \frac{111.021(\text{dB}\mu\text{V}/\text{m}) - 120}{20} \right\}}$$

$$E \left(\frac{V}{m} \right) = 3.556 * 10^{-1} \text{V/m}$$

The power density of measurement point 1 in units of W/m^2 was then calculated using the equation below

$$S(W/m^2) = \frac{E^2 \left(\frac{V}{m} \right)}{377}$$

$$S(W/m^2) = \frac{(3.556 * 10^{-1})^2}{377}$$

$$S(W/m^2) = 3.354 * 10^{-4} W/m^2$$

The results of the power density levels at the various measurement points of the transmitting manpack antennas are shown in Table C2.

The power density of the base station transmitting antenna is calculated using the equation below:

$$S = \frac{E_{avg}^2}{377} \dots \dots \dots (3.6)$$

$$S = \frac{0.1265059}{377}$$

$$S = 3.355 * 10^{-4} W/m^2$$

Uncertainty Estimation

The combined standard uncertainty $u_c(E_{avg})$ estimation for the base station antenna was calculated with the equation below:

$$u_c(E_{avg}) = \sqrt{\sum_{i=1}^n (c_i * u_{(xi)})^2}$$

Where the sensitivity coefficient of the type –B uncertainty, $C_i = 1$ (xi) is the uncertainty contributor at frequency i and $u_{(xi)}$ is the standard uncertainty due to the contributor(xi) at the same frequency (Table D1)

$$\text{Let } \sum_{i=1}^n (c_i * u_{(xi)})^2 = \alpha$$

$$\alpha = (1 \times 2.96)^2 + (1 \times 10)^2 + (1 \times 2.58)^2 + (1 \times 2.98)^2 + (1 \times 0.84)^2 \\ + (1 \times 0.05)^2$$

$$= 25.0165$$

$$u_c(E_{avg}) = \sqrt{\alpha}$$

$$u_c(E_{avg}) = \sqrt{25.0165}$$

$$u_c(E_{avg}) = 5.00 \%$$

The expanded uncertainty is also expressed as:

$$u(S) = 1.96 \times u_c(E_{avg})$$

$$u(S) = 1.96 \times 5.00 \%$$

$$u(S) = 9.80 \%$$

The power density of the base station antenna transmitting at a frequency of 5.5261 MHz is $3.355 \times 10^{-4} \pm 3.288 \times 10^{-5} \text{ W/m}^2$

A3. Real-time Measurement of vehicle-mounted antenna

The electric field strength at the driver's seat was measured in dB μ V/m as 88.44dB μ V/m from the vehicle-mounted antenna. The field strength in dB μ V/m was converted to the standardize electric field strength in units of V/m using the equation below

$$E\left(\frac{V}{m}\right) = 10^{\left\{\frac{E(dB\mu V/m)-120}{20}\right\}}$$

$$E\left(\frac{V}{m}\right) = 10^{\left\{\frac{88.45(dB\mu V/m)-120}{20}\right\}}$$

$$E\left(\frac{V}{m}\right) = 2.644 * 10^{-2} \text{ V/m}$$

The power density at the driver's seat in units of W/m² was then calculated using the equation below

$$S(W/m^2) = \frac{E^2\left(\frac{V}{m}\right)}{377}$$

$$S(W/m^2) = \frac{(2.644 * 10^{-2})^2}{377}$$

$$S(W/m^2) = 1.854 * 10^{-6} \text{ W/m}^2$$

The results of the power density levels at the various substation antennas are shown in Table C3.

The power density of the vehicle-mounted transmitting antenna is calculated using the equation below:

$$S = \frac{E_{avg}^2}{377} \dots \dots \dots (3.6)$$

$$S = \frac{0.002341475}{377}$$

$$S = 6.210 \times 10^{-6} \text{ W/m}^2$$

Uncertainty Estimation

The combined standard uncertainty $u_c(E_{avg})$ estimation for the base station antenna was

calculated with the equation below:

$$u_c(E_{avg}) = \sqrt{\sum_{i=1}^n (c_i * u_{(xi)})^2}$$

Where the sensitivity coefficient of the type –B uncertainty, $C_i = 1$ (xi) is the uncertainty contributor at frequency i and $u_{(xi)}$ is the standard uncertainty due to the contributor(xi) at the same frequency (Table D1)

$$\text{Let } \sum_{i=1}^n (c_i * u_{(xi)})^2 = \alpha$$

$$\begin{aligned} \alpha &= (1 \times 2.96)^2 + (1 \times 10)^2 + (1 \times 2.58)^2 + (1 \times 2.98)^2 + (1 \times 0.84)^2 \\ &\quad + (1 \times 0.05)^2 \\ &= 25.0165 \end{aligned}$$

$$u_c(E_{avg}) = \sqrt{\alpha}$$

$$u_c(E_{avg}) = \sqrt{25.0165}$$

$$u_c(E_{avg}) = 5.00 \%$$

The expanded uncertainty is also expressed as:

$$u(S) = 1.96 \times u_c(E_{avg})$$

$$u(S) = 1.96 \times 5.00 \%$$

$$u(S) = 9.80 \%$$

The power density of the base station antenna transmitting at a frequency of 5.5261 MHz is $6.210 \times 10^{-6} \pm 6.086 \times 10^{-7} \text{ W/m}^2$

A4. Real-time Measurement in the operations room relative to a base station antenna

Measurement of the electric field from the operator's seat relative to the base station antenna, the field strength in dB μ V/m across 50 Ω was measured as 92.937 dB μ V/m. The field strength in dB μ V/m was converted to the standardize electric field strength in units of V/m using the equation below:

$$E \left(\frac{V}{m} \right) = 10^{\left\{ \frac{E(\text{dB}\mu\text{V}/m) - 120}{20} \right\}}$$

$$E \left(\frac{V}{m} \right) = 10^{\left\{ \frac{92.937(\text{dB}\mu\text{V}/m) - 120}{20} \right\}}$$

$$E \left(\frac{V}{m} \right) = 4.434 \times 10^{-2} \text{ V/m}$$

The power density of the operations room in units of W/m^2 was then calculated using the equation below:

$$S(\text{W/m}^2) = \frac{E^2 \left(\frac{V}{m} \right)}{377}$$

$$S(W/m^2) = \frac{(4.434 * 10^{-2})^2}{377}$$

$$S(W/m^2) = 5.214 * 10^{-8} W/m^2$$

The results of the power density levels at the various substation antennas are shown in Table C4.

The power density of the base station transmitting antenna is calculated using the equation below:

$$S = \frac{E_{avg}^2}{377} \dots \dots \dots (3.6)$$

$$S = \frac{0.002144713}{377}$$

$$S = 5.688 \times 10^{-6} W/m^2$$

Uncertainty Estimation

The combined standard uncertainty $u_c(E_{avg})$ estimation for the base station antenna was calculated with the equation below:

$$u_c(E_{avg}) = \sqrt{\sum_{i=1}^n (c_i * u_{(xi)})^2}$$

Where the sensitivity coefficient of the type –B uncertainty, $C_i = 1$ (xi) is the uncertainty contributor at frequency i and $u_{(xi)}$ is the standard uncertainty due to the contributor(xi) at the same frequency (Table D1)

$$\text{Let } \sum_{i=1}^n (c_i * u_{(xi)})^2 = \alpha$$

$$\alpha = (1 \times 2.96)^2 + (1 \times 10)^2 + (1 \times 2.58)^2 + (1 \times 2.98)^2 + (1 \times 0.84)^2 + (1 \times 0.05)^2$$

$$= 25.0165$$

$$u_c(E_{avg}) = \sqrt{\alpha}$$

$$u_c(E_{avg}) = \sqrt{25.0165}$$

$$u_c(E_{avg}) = 5.00 \%$$

The expanded uncertainty is also expressed as:

$$u(S) = 1.96 \times u_c(E_{avg})$$

$$u(S) = 1.96 \times 5.00 \%$$

$$u(S) = 9.80 \%$$

The power density of the base station antenna transmitting at a frequency of 5.5261 MHz is $5.688 \times 10^{-6} \pm 5.575 \times 10^{-7} \text{ W/m}^2$

A5. Exposure Quotient

According to (ICNIRP, 1998), there are no reference power density levels for occupational and general public exposure between the frequency ranges of 1-10MHz.

Rather the reference electric field strength for occupational ($610/f$) and general public exposure $87/f^{1/2}$ were used. The operating frequency used throughout the measurement is 5.5261 MHz. The occupational and general public exposure quotient of the base station radiating antenna was calculated as

$$\text{Exposure Quotient} = \frac{E_{meas}}{E_{ICNIRP}}$$

Where $E_{total,meas}$ is the total electric field strength and E_{ICNIRP} is the calculated ICNIRP electric field reference level.

Exposure Quotient for base station

$$E_{total,meas} = 0.018503909$$

$$E_{ICNIRP} = 610/f$$

$$\text{Occupational Exposure Quotient} = \frac{0.018503909}{110.38 \times 10^6}$$

$$= 1.676 \times 10^{-10}$$

$$E_{total,meas} = 0.018503909$$

$$E_{ICNIRP} = 87/f^{1/2}$$

$$= 4.978522944$$

$$\begin{aligned} \text{Public Exposure Quotient} &= \frac{0.018503909}{4.978522944} \\ &= 3.716 \times 10^{-3} \end{aligned}$$

Exposure Quotient for manpack radio

$$E_{total, meas} = 0.3556766$$

$$E_{ICNIRP} = 610/f$$

$$\begin{aligned} \text{Occupational Exposure Quotient} &= \frac{0.3556766}{110.38 \times 10^6} \\ &= 3.222 \times 10^{-9} \end{aligned}$$

$$E_{total, meas} = 0.3556766$$

$$E_{ICNIRP} = 87/f^{1/2}$$

$$= 4.978522944$$

$$\begin{aligned} \text{Public Exposure Quotient} &= \frac{0.3556766}{4.978522944} \\ &= 7.144 \times 10^{-2} \end{aligned}$$

Exposure Quotient for vehicle-mounted radio

$$E_{total, meas} = 0.048388787$$

$$E_{ICNIRP} = 610/f$$

$$\text{Occupational Exposure Quotient} = \frac{0.048388787}{110.38 \times 10^6}$$

$$= 2.675 \times 10^{-14}$$

$$E_{total, meas} = 0.048388787$$

$$E_{ICNIRP} = 87/f^{1/2}$$

$$= 4.978522944$$

$$\text{Public Exposure Quotient} = \frac{0.048388787}{4.978522944}$$

$$= 9.719 \times 10^{-3}$$

APPENDIX B: EM FIELDS EXPOSURE REFERENCE LEVELS

Table B4 ICNIRP reference levels (unperturbed RMS values) (ICNIRP, 1998)

Types of exposure	Frequency range	E-field strength (Vm ⁻¹)	H-field strength (Am ⁻¹)	Equivalent plane wave power density $S_{eq}(W/m^{-2})$
Occupational Exposure	Up to 1Hz		1.63×10^5	
	1-8Hz	20 000	$1.63 \times 10^5/f^2$	
	0.025-0.82kHz	$500/f$	$20/f$	
	0.82-65kHz	610	24.4	-
	0.065-1MHz	610	$1.6/f$	-
	1-10MHz	$610/f$	$1.6/f$	-
	10-400MHZ	61	0.16	10
	400-2000MHz	$3 f^{0.5}$	$0.008/f^{0.5}$	$f/40$
	2-300GHz	137	0.36	50
Public Exposure	Up to 1 Hz	-	3.2×10^4	
	1-8 Hz	10 000	$3.2 \times 10^4/f^2$	
	8-25 Hz	10 000	$4000/f$	
	0.025-0.8 kHz	$250/f$	$4/f$	-
	0.8-3 kHz	$250/f$	5	-
	3-150 kHz	87	5	-
	0.15-1 MHz	87	$0.73/f$	-
	1-10 MHZ	$87/ f^{0.5}$	$0.73/f$	-
	10-400 MHZ	28	0.073	
	400-2000 MHz	$1.375 f^{0.5}$	$0.0037f^{0.5}$	$f/200$
	2-300 GHz	61	0.16	10

***NOTE**

1. f as indicated in the frequency range column
2. For frequencies between 100 kHz and 10 GHz, the averaging time is 6 minutes.
3. For frequencies up to 100 kHz, the peak values can be obtained by multiplying the RMS value by $\sqrt{2}$. For a pulse of duration tp , the equivalent frequency to apply should be calculated as $f = 1/(2tp)$.
4. Between 100 kHz and 10 MHz, peak values for the field strength are obtained by interpolation from the 1.5-fold peak at 100 MHz to the 32-fold peak at 10 MHz. for frequencies exceeding 10 MHz, it is suggested that the peak equivalent plane-wave power density, as averaged over the pulse width, does not exceed 1000 times the Seq, limit or that the field strength does not exceed the field strength exposure levels given in the table.
5. For frequencies exceeding 10 GHz, the averaging time is $68/f^{1.05}$ minutes (f in GHz).

**Table B2. Some quantities and SI-units used in the radiofrequency band
(ICNIRP, 2009)**

QUANTITY	SYMBOL	SI-UNIT	SYMBOL
Conductivity	Σ	Siemens per meter	$S.m^{-1}$
Permittivity	E	Farad per meter	$F.m^{-1}$
Current	I	Ampere	A
Current density	J	Ampere per square meter	$A.m^{-2}$
Electric field strength	E	Volt per meter	$V.m^{-1}$
Power density	S	Watt per square meter	$W.m^{-2}$
Frequency	F	Hertz	Hz
Impedance	Z	Ohm	Ω
Magnetic field strength	H	ampere per kilogram	$A.kg^{-1}$
Propagation constant	K	Per meter	m^{-1}
Specific absorption	SA	Joule per kilogram	$J.kg^{-1}$
Specific absorption rate	SAR	Watt per kilogram	$W.kg^{-1}$
Wavelength	Λ	Meter	M
Magnetic flux density	B	Tesla	T

APPENDIX C. MEASUREMENTS TABLES**Table C1. Measurement of Electric Field Strength of a base station radio with an operating frequency of 5.52 MHz**

Base Station	GPS Coordinate		Electric Field Strength(Raw)	Electric Field Strength(Corrected)	Radial Distance	Calculated Power Density
	Lat	Log	E Field (dB μ V)	E Field (V/m)	m	S(W/m ²)
0	N 5 35 16	W 0 9 22	85.33	0.018471408	19	9.05021E-07
1	N 5 35 17	W 0 9 21	51.84	0.000390841	38	4.0519E-10
2	N 5 35 15	W 0 9 22	57.57	0.000755962	54	1.51586E-09
3	N 5 35 16	W 0 9 19	35.27	5.80096E-05	101	8.92604E-12
4	N 5 35 20	W 0 9 22	43.91	0.000156856	103	6.52617E-11
5	N 5 35 20	W 0 9 24	28.83	2.76376E-05	116	2.02609E-12
6	N 5 35 13	W 0 9 21	55.51	0.000596348	123	9.43319E-10
7	N 5 35 21	W 0 9 24	43.08	0.000142561	145	5.39087E-11
8	N 5 35 14	W 0 9 18	37.83	7.78933E-05	153	1.60938E-11
9	N 5 35 22	W 0 9 23	44.46	0.000167109	166	7.40728E-11
10	N 5 35 22	W 0 9 26	26.89	2.21055E-05	201	1.29616E-12
11	N 5 35 23	W 0 9 24	42.05	0.000126619	203	4.25264E-11
12	N 5 35 23	W 0 9 24	42.05	0.000126619	203	4.25264E-11
13	N 5 35 25	W 0 9 25	37.98	7.92501E-05	271	1.66594E-11

Table C2. Measurement of Electric Field Strength of an operations room with an operating frequency of 5.52 MHz

	GPS Coordinate		Electric Field Strength(Raw)	Electric Field Strength(Corrected)	Radial Distance (m)	Calculated Power Density
	Lat	Log	Efield (dB μ V)	E Field (V/m)		S(W/m ²)
Entrance	N 5 35 16	W 0 9 21	59.505	0.000944604	5	2.36678E-09
Ops seat	N 5 35 17	W 0 9 21	92.937	0.044345545	7	5.21625E-06
Any other loc in ops room	N 5 35 17	W 0 9 21	82.465	0.013281588	10	4.67906E-07
Exit	N 5 35 16	W 0 9 21	59.505	0.000944604	5	2.36678E-09

Table C3. Measurement of Electric Field Strength of a manpack radio with an operating frequency of 5.52 MHz

Base Station	GPS Coordinate		Electric Field Strength(Raw)	Electric Field Strength (Corrected)	Radial Distance (m)	Calculated Power Density
	Lat	Log	Efield (dB μ V)	E Field (V/m)		S(W/m ²)
Patrol Base	N 5 35 16	W 0 9 22	111.021	0.35567226	0	0.000335551
Patrol team 1	N 5 36 16	W 0 9 22	64.781	0.001734	10	7.97551E-09
Patrol team 2	N 5 35 16	W 0 9 22	44.481	0.00016751	15	7.44318E-11
Patrol team 3	N 5 35 16	W 0 9 22	45.773	0.00019438	28	1.00221E-10
Patrol team 4	N 5 35 16	W 0 9 22	41.421	0.00011777	30	3.67924E-11
Patrol team 5	N 5 35 15	W 0 9 22	37.881	7.8352E-05	62	1.62839E-11

Table C4. Measurement of Electric Field Strength of a vehicle-mounted radio with an operating frequency of 5.52 MHz

Location	GPS Coordinates		Electric Field Strength (Raw)	Electric Field Strength (Corrected)	Calculated Power density
	Lat	Long	Efield (dB μ V)	E Field (V/m)	S(W/m ²)
Commander's Seat	N 5 35 23	W 0 9 22	76.433	0.006632084	1.1667E-07
Driver's Seat	N 5 35 23	W 0 9 22	88.445	0.026439303	1.85421E-06
Escort's Seat	N 5 35 23	W 0 9 22	92.037	0.039980664	4.23993E-06

APPENDIX D: LEVELS OF UNCERTAINTY

Table D1. The uncertainty associated with the electric field measurement.

Uncertainty sources	Uncertainty type	Estimate (%)	Probability distribution	Divisor	Standard uncertainty (%)
Spectrum analyzer					
Amplitude accuracy	B	5.92	Rectangular	2.00	2.96
Resolution bandwidth (@ 200 kHz)	B	0.20	Normal	2.00	0.10
Mismatch (analyzer and antenna)	B	3.64	U-shape	1.41	2.58
Antenna calibration factors	B	5.95	Normal	2.00	2.98
Cable correction factor	B	1.45	Rectangular	1.73	0.84
Measurement repeatability	A	0.10	Normal	2.00	0.05
Combined uncertainty (%)		Coverage factor			9.51
Expanded uncertainty (95%)			1.96		18.64

APPENDIX E. ESTIMATED POWER DENSITY LEVELS, ELECTRIC FIELD STRENGTH AND EXPOSURE QUOTIENT

Table E1. Estimated power density levels from measured electric field strength

Scenario	Power density ($\frac{W}{m^2}$)
1	$9.08 \times 10^{-7} \pm 8.90 \times 10^{-8}$
2	$3.35 \times 10^{-4} \pm 3.28 \times 10^{-5}$
3	$6.21 \times 10^{-6} \pm 6.08 \times 10^{-7}$
4	$5.68 \times 10^{-6} \pm 5.57 \times 10^{-7}$

Table E2. Antenna electric field strength measured

Scenario	Electric Field Strength (V/m)
1	$3.42 \times 10^{-4} \pm 3.35 \times 10^{-5}$
2	$1.26 \times 10^{-1} \pm 1.23 \times 10^{-2}$
3	$2.34 \times 10^{-3} \pm 2.33 \times 10^{-4}$
4	$2.14 \times 10^{-3} \pm 2.10 \times 10^{-4}$

Table E3. Estimated exposure quotient from measured electric field strength

Scenario	Occupational Exposure Quotient	General public Exposure
Base station	1.67×10^{-10}	3.22×10^{-9}
Manpack	3.22×10^{-9}	7.14×10^{-2}
Vehicle-mounted	2.67×10^{-14}	9.71×10^{-3}

APPENDIX F. SPECTRUM ANALYZER GRAPHS

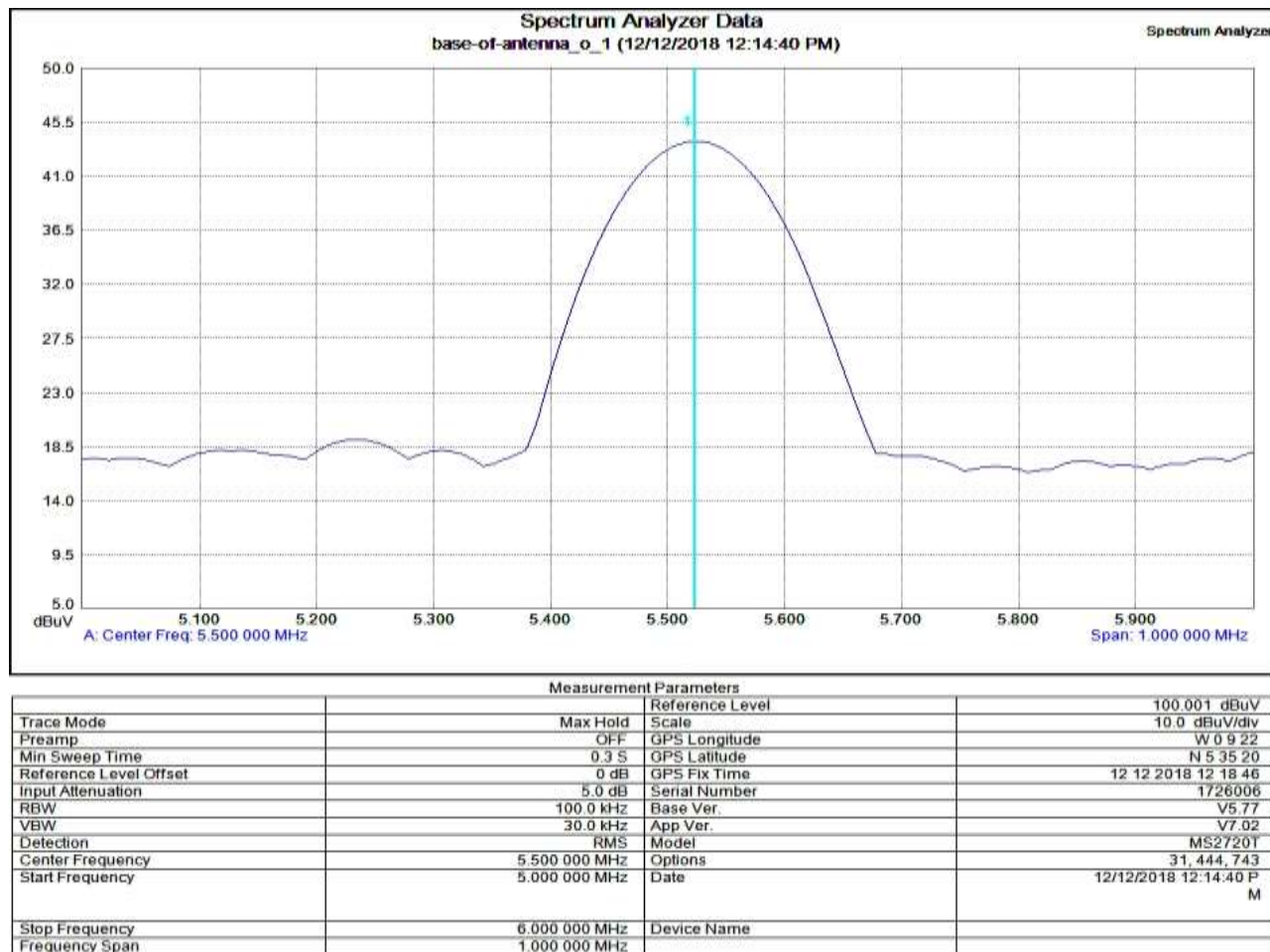
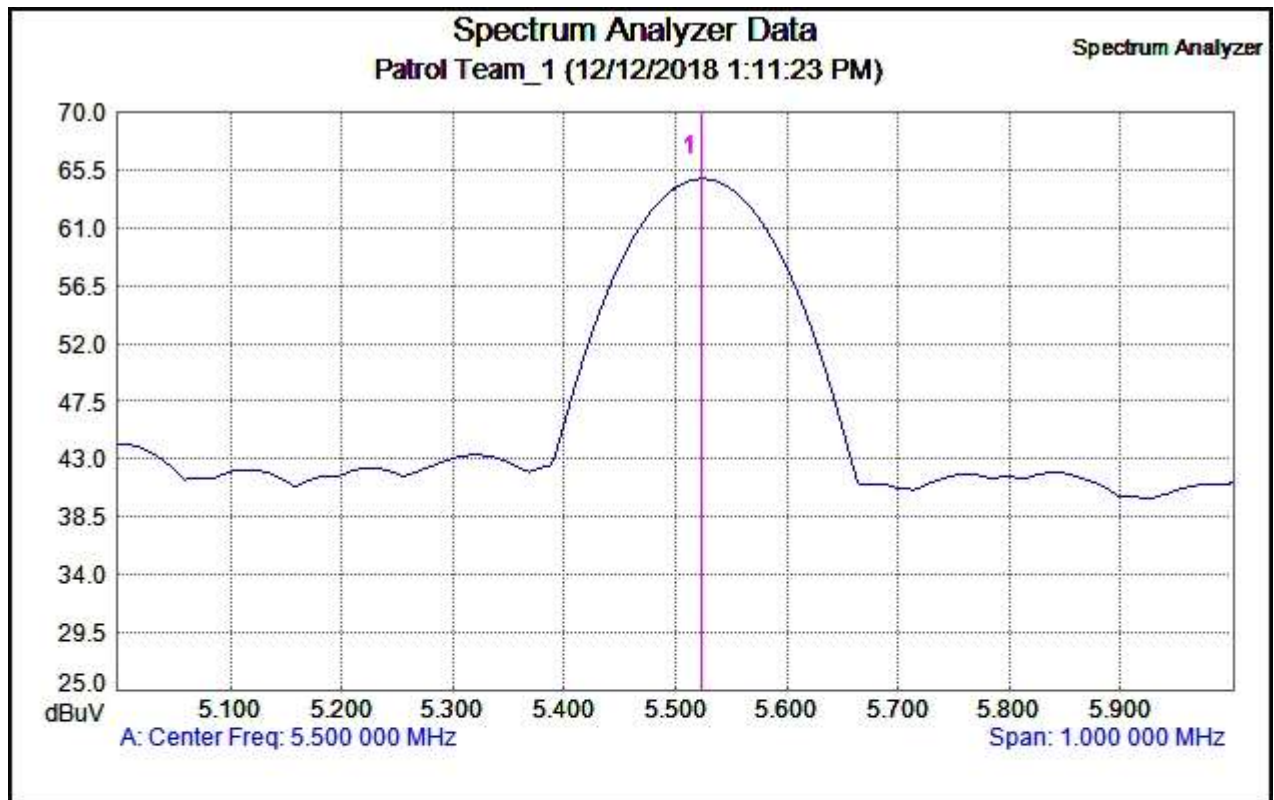
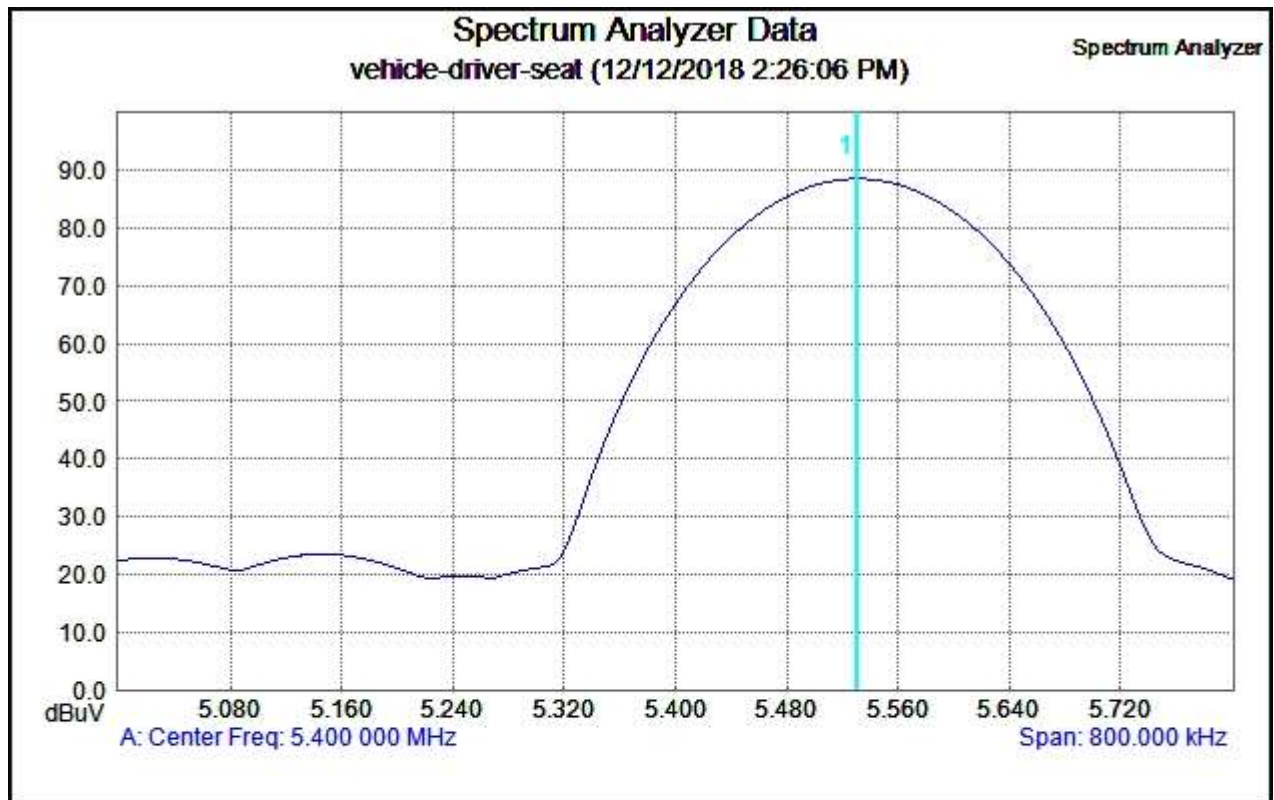


Fig F1: Spectrum location 1 for a base station antenna at 5.52 MHz



Measurement Parameters			
Trace Mode	Max Hold	Reference Level	119.999 dBuV
Preamp	OFF	Scale	10.0 dBuV/div
Min Sweep Time	0.3 S	GPS Longitude	W 0 9 22
Reference Level Offset	0 dB	GPS Latitude	N 5 35 16
Input Attenuation	30.0 dB	GPS Fix Time	12 12 2018 13 15 30
RBW	100.0 kHz	Serial Number	1726006
VBW	30.0 kHz	Base Ver.	V5.77
Detection	RMS	App Ver.	V7.02
Center Frequency	5.500 000 MHz	Model	MS2720T
Start Frequency	5.000 000 MHz	Options	31, 444, 743
Stop Frequency	6.000 000 MHz	Date	12/12/2018 1:11:23 PM
Frequency Span	1.000 000 MHz	Device Name	

Fig F2: Spectrum location 1 for a Manpack radio antenna at 5.52 MHz



Measurement Parameters			
Trace Mode	Max Hold	Reference Level	100.001 dBuV
Preamp	OFF	Scale	10.0 dBuV/div
Min Sweep Time	0.3 S	GPS Longitude	W 0 9 22
Reference Level Offset	0 dB	GPS Latitude	N 5 35 23
Input Attenuation	5.0 dB	GPS Fix Time	12 12 2018 14 30 13
RBW	100.0 kHz	Serial Number	1726006
VBW	30.0 kHz	Base Ver.	V5.77
Detection	RMS	App Ver.	V7.02
Center Frequency	5.400 000 MHz	Model	MS2720T
Start Frequency	5.000 000 MHz	Options	31, 444, 743
Stop Frequency	5.800 000 MHz	Date	12/12/2018 2:26:06 PM
Frequency Span	800.000 000 kHz	Device Name	

Fig F3: Spectrum location of driver's seat for vehicle-mounted radio antenna at 5.52 MHz

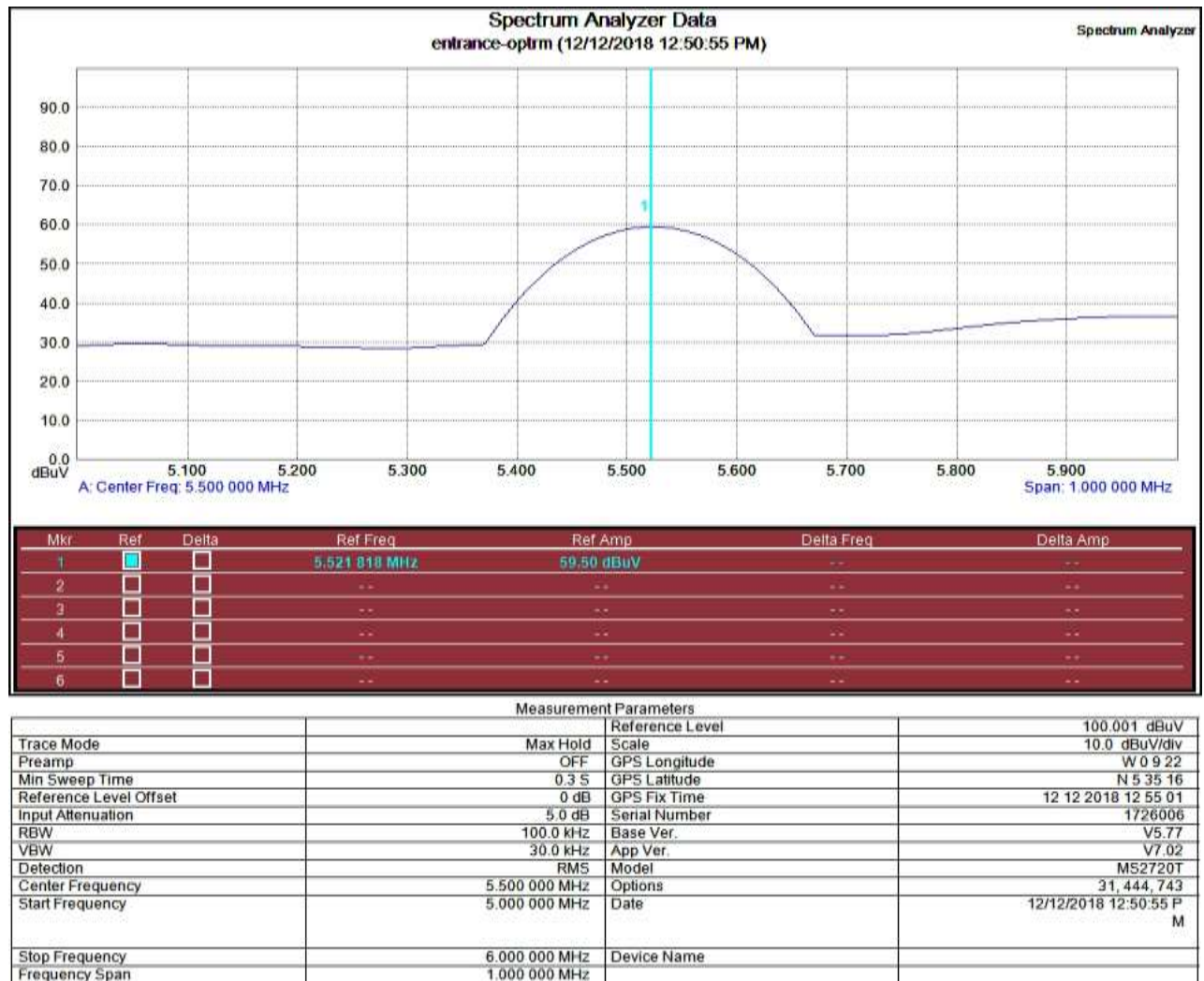


Fig F4: Spectrum location of the entrance of operations room



SAR MEASUREMENT REPORT

Project name :

RADIO _4HH

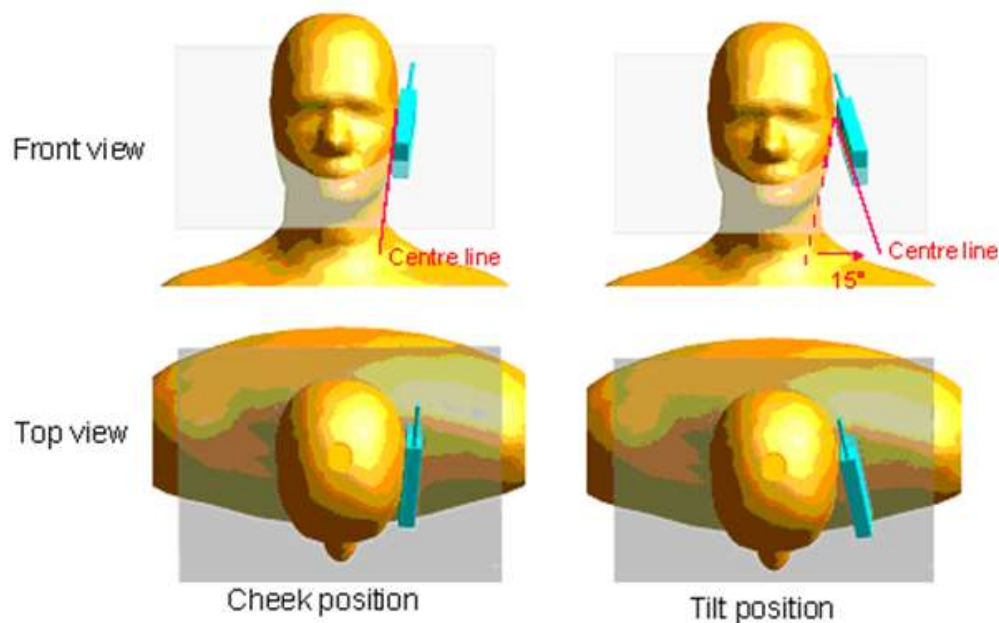
APPENDIX G**G1. INFORMATION ON THE TESTING****I. INFORMATIONS ON THE TESTING****I.1. Normative reference**

IEEE 1528-2013: Recommended Practice for determining the Peak Spatial-Average Specific Absorption Rate (SAR) in the Human Head from Wireless Communications Devices: Measurement Techniques.

I.3. Positions and test conditions of the mobile phone under test

The mobile phone antenna and battery are those specified by the manufacturer. The battery is fully charged before each measurement. The output power and frequency are controlled using a base station simulator. The mobile phone is set to transmit at its highest output peak power level.

The mobile phone is test in the “cheek” and “tilted” positions on the left and right sides of the phantom. The mobile phone is placed with the vertical centre line of the body of the mobile phone and the horizontal line crossing the centre of the earpiece in a plane parallel to the sagittal plane of the phantom.



Description of the « cheek » position:

The mobile phone is well placed in the reference plane and the earpiece is in contact with the ear. Then the mobile phone is moved until any point on the front side get in contact with the cheek of the phantom or until contact with the ear is lost.

Description of the « tilted » position:

The mobile phone is well place in the “cheek” position as described above. Then the mobile phone is moved outward away from the mouth by an angle of 15 degrees or until contact with the ear lost.

G2. THE MEASUREMENT SYSTEM

Comosar is a system that is able to determine the SAR distribution inside a phantom of human being according to different standards. The Comosar system consists of the following items:

- Main computer to control all the system
- 6 axis robot
- Data acquisition system
- Miniature E-field probe
- Phone holder
- Head simulating tissue

The following figure shows the system.



COMOSAR bench

The mobile phone under test operating at the maximum power level is placed in the phone holder, under the phantom, which is filled with head simulating liquid. The E-Field probe measures the electric field inside the phantom. The OpenSAR software computes the results to give a SAR value in a 1g or 10 g mass.

II.1. Phantom

For the measurements the Specific Anthropomorphic Mannequin (SAM) defined by the IEEE SCC-34/SC2 group is used. The phantom is a polyurethane shell integrated in a wooden table. The thickness of the phantom amounts to 2 mm +/- 0,2 mm. It enables the dosimetric evaluation of left and right hand phone usage and includes an additional flat phantom part for the simplified performance check. The phantom set-up includes a cover, which prevents the evaporation of the liquid.

II.2. Probe

For the measurements the Specific Dosimetric E-Field Probe SSE5 or SSE2 with following specifications is used.

- Dynamic range: 0.01-100 W/kg
- Tip Diameter : 5 mm for SSE5 and 2 mm for SSE2

- Distance between probe tip and sensor center : 2.5 mm for SSE5 and 1 mm for SSE2
- Distance between sensor center and the inner phantom surface: 4 mm for $f < 4\text{GHz}$ (repeatability better than $\pm 1\text{mm}$), 2 mm for $f \geq 4\text{GHz}$ (repeatability better than $\pm 0.5\text{mm}$)
- Probe linearity : $< 0.25\text{ dB}$
- Axial Isotropy : $< 0.25\text{ dB}$
- Spherical Isotropy : $< 0.50\text{ dB}$
- Calibration range : 150 to 6000 MHz for head & body simulating liquid
- Angle between probe axis (evaluation axis) and surface normal line : less than 20°

II.3. Measurement procedure

The following steps are used for each test position

- Establish a call with the maximum output power with a base station simulator. The connection between the mobile and the base station simulator is established via air interface
- Measurement of the local E-field value at a fixed location. This value serves as a reference value for calculating a possible power drift.
- Measurement of the SAR distribution with a grid of 8 to 16 mm * 8 to 16 mm and a constant distance to the inner surface of the phantom. Since the sensors can not directly measure at the inner phantom surface, the values between the sensors and the inner phantom surface are extrapolated. With these values the area of the maximum SAR is calculated by an interpolation scheme.
- Around this point, a cube of 24 * 24 * 24 mm, 30 * 30 * 30 mm or 32 * 32 * 32 mm is assessed by measuring with 4 to 8 mm step in X and Y and 2 to 5 mm step in Z. With these data, the peak spatial-average SAR value can be calculated.

II.4 Description of interpolation/extrapolation scheme

The local SAR inside the phantom is measured using small dipole sensing elements inside a probe body. The probe tip must not be in contact with the phantom surface in order to minimize measurements errors, but the highest local SAR will occur at the surface of the phantom.

An extrapolation is using to determinate this highest local SAR values.

The extrapolation is based on a fourth-order least-square polynomial fit of measured data. The local SAR value is then extrapolated from the liquid surface with a 1 mm step.

The measurements have to be performed over a limited time (due to the duration of the battery) so the step of measurement is high. It could vary between 2 to 8 mm. To obtain an accurate assessment of the maximum SAR averaged over 10 grams and 1 gram requires a very fine resolution in the three dimensional scanned data array.

An interpolation is using to provide an array of sufficient resolution.

The measured and extrapolated SAR values are interpolated on a 1 mm grid with a three dimensional thin plate spline algorithm.

Table G3. UNCERTAINTY ASSESSMENT

The following table includes the uncertainty table of the IEEE1528/IEC62209. The values are determined by Satimo.

UNCERTAINTY EVALUATION FOR HANDSET SAR TEST

A	c	d	e= f(d,k)	f	g	h= c*f/e	i= c*g/e	k
Uncertainty Component	Tol (+-%)	Prob Dist.	Div.	Ci (1g)	Ci (10g)	1g Ui (+-%)	10g Ui (+-%)	Vi
Measurement System								
Probe Calibration	5.8	N	□	1	1	5.80	5.80	□.
Axial Isotropy	3.5	R	□□	(1_Cp) ^1/2	(1_Cp) ^1/2	1.43	1.43	□.
Hemispherical Isotropy	5.9	R	□□	(Cp)^ 1/2	(Cp)^ 1/2	2.41	2.41	□.
Boundary Effect	1.0	R	□□	1	1	0.58	0.58	□.
Linearity	4.7	R	□□	1	1	2.71	2.71	□.
System Detection Limits	1.0	R	□□	1	1	0.58	0.58	□.
Modulation response	3.00	R	□□	1	1	1.73	1.73	□.
Readout Electronics	0.50	N	□	1	1	0.50	0.50	□.
Response Time	0.0	R	□□	1	1	0.00	0.00	□.
Integration Time	1.4	R	□□	1	1	0.81	0.81	□.
RF Ambient Conditions - Noise	3.0	R	□□	1	1	1.73	1.73	□.
RF Ambient Conditions - Reflections	3.0	R	□□	1	1	1.73	1.73	□.
Probe Positioner	1.4	R	□□	1	1	0.81	0.81	□.
Mechanical Tolerance								
Probe Positioning with respect to Phantom Shell	1.40	R	□□	1	1	0.81	0.81	□.
Extrapolation, interpolation and integration Algorithms for Max. SAR Evaluation	2.3	R	□□	1	1	1.33	1.33	□.
Test sample Related								
Test sample positioning	2.60	N	□	1	1	2.60	2.60	□ □
Device Holder Uncertainty	3.00	N	□	1	1	3.00	3.00	□.

Output power Variation - SAR drift measurement	5.00	R	□□	1	1	2.89	2.89	□.
SAR scaling	2.00	R	□□	1	1	1.15	1.15	
Phantom and Tissue Parameters								
Phantom Shell Uncertainty - Shape, Thickness and Permittivity	4.00	R	□□	1	1	2.31	2.31	□.
Uncertainty in SAR correction for deviation in permittivity and conductivity	2.00	N	□	1	0.84	2.00	1.68	□.
Liquid Conductivity - Temperature Uncertainty	2.50	R	□□	0.78	0.71	1.13	1.02	□.
Liquid Conductivity Measurement	4.00	N	□	0.78	0.71	3.12	2.84	□.
Liquid Permittivity - Temperature Uncertainty	2.50	R	□□	0.23	0.26	0.33	0.38	□.
Liquid Permittivity Measurement	5.00	N	□	0.23	0.26	1.15	1.30	□.
Combined Standard Uncertainty		RSS				10.47	10.34	
Expanded Uncertainty (95% Confidence interval)		k				20.95	20.69	

Table G4. UNCERTAINTY FOR SYSTEM PERFORMANCE CHECK

A	c	d	e= f(d,k)	f	g	h= c*f/e	i= c*g/e	k
Uncertainty Component	Tol (+ - %)	Prob · Dist.	Div.	Ci (1g)	Ci (10g)	1g Ui (+-%)	10g Ui (+-%)	Vi
Measurement System								
Probe Calibration	5.8	N	□	1	1	5.80	5.80	□.
Axial Isotropy	3.5	R	□□	1	1	2.02	2.02	□.
Hemispherical Isotropy	5.9	R	□□	0	0	0.0	0.0	□.
Boundary Effect	1.0	R	□□	1	1	0.58	0.58	□.
Linearity	4.7	R	□□	1	1	2.71	2.71	□.
System Detection Limits	1.0	R	□□	1	1	0.58	0.58	□.
Modulation response	0.00	N	□□	0	0	0.00	0.00	□.
Readout Electronics	0.50	N	□	1	1	0.50	0.50	□.
Response Time	0.0	R	□□	0	0	0.00	0.00	□.

Integration Time	1.4	R	□□	0	0	0.0	0.0	□.
RF Ambient Conditions - Noise	3.0	R	□□	1	1	1.73	1.73	□.
RF Ambient Conditions - Reflections	3.0	R	□□	1	1	1.73	1.73	□.
Probe Positioner Mechanical Tolerance	1.4	R	□□	1	1	0.81	0.81	□.
Probe Positioning with respect to Phantom Shell	1.40	R	□□	1	1	0.81	0.81	□.
Extrapolation, interpolation and integration Algorithms for Max. SAR Evaluation	2.3	R	□□	1	1	1.33	1.33	□.
Dipole								
Deviation of experimental source from numerical source	5.00	N	□	1	1	5.00	5.00	□.
Input Power and SAR drift measurement	0.50	R	□□	1	1	0.29	0.29	□.
Dipole Axis to Liquid Distance	2.00	R	□□	1	1	1.15	1.15	□.
Phantom and Tissue Parameters								
Phantom Shell Uncertainty - Shape, Thickness and Permittivity	4.00	R	□□	1	1	2.31	2.31	□.
Uncertainty in SAR correction for deviation in permittivity and conductivity	2.00	N	□	1	0.84	2.00	1.68	□.
Liquid Conductivity - Temperature Uncertainty	2.50	R	□□	0.78	0.71	1.13	1.02	□.
Liquid Conductivity Measurement	4.00	N	□	0.78	0.71	3.12	2.84	□.
Liquid Permittivity - Temperature Uncertainty	2.50	R	□□	0.23	0.26	0.33	0.38	□.
Liquid Permittivity Measurement	5.00	N	□	0.23	0.26	1.15	1.30	□.
Combined Standard Uncertainty		RSS				10.16	10.03	
Expanded Uncertainty (95% Confidence interval)		k				20.32	20.06	

Table G 5. RESULTS ON VALIDATION TEST

<u>TYPE</u>	<u>BAND</u>	<u>PARAMETERS</u>
Validation	CW750	<u>Measurement 1: Validation Plane with Dipole device position on Middle Channel in CW mode</u>

MEASUREMENT 1

DIPOLE EVALUATION Type: Validation measurement (Complete)

Date of measurement: 8/5/2019

Measurement duration: 14 minutes 41 seconds

Mobile Phone IMEI number: -

Table G5.1 Experimental conditions.

<u>Area Scan</u>	<u>surf_sam_plan.txt, h= 5.00 mm</u>
<u>Zoom Scan</u>	<u>5x5x7,dx=8mm dy=8mm</u> <u>dz=5mm,Complete/nsurf_sam_plan.txt, h= 5.00 mm</u>
<u>Phantom</u>	<u>Validation plane</u>
<u>Device Position</u>	<u>Dipole</u>
<u>Band</u>	<u>CW750</u>
<u>Channels</u>	<u>Middle</u>
<u>Signal</u>	<u>CW (Crest factor: 1.0)</u>

Table G5.2 Instrumentations.

Equipment description	Manufacturer/ Model	Identification No.	Current calibration date	Next calibration date
SAR Probe	SATIMO	SN_0816_EPGO2 88/nCF: 1.44	11/2016	11/2017
Phantom	SATIMO	SN_4316_SAM13 0	Validated. No cal required.	Validated. No cal required.
Liquid	SATIMO	-	7/8/2014	-
Amplifier	MVG	143060	14/11/2016	13/11/2017
Power Meter	NI	832839/056	06/10/2016	05/10/2017
VNA	Anritsu	MS2025B	-	-

Table G5.3 SAR Measurement Results

Middle Band SAR (Channel -1):

Frequency (MHz)	750.000000
Relative permittivity (real part)	41.900002
Relative permittivity (imaginary part)	21.360001
Conductivity (S/m)	0.890000
Variation (%)	-4.160000