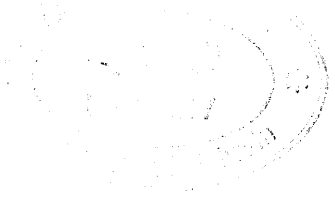
Measurement and Analysis of Radiofrequency Radiation Levels from Mobile Phone Base Stations in the Kingdom of Bahrain



By

Hasan Ali Abdulla Al-Najjar

A Thesis submitted in partial fulfillment of the requirements for the degree of

Master of Science
In Environment and Sustainable Development

Supervised by:

Prof. Dr. Waheeb Essa Alnaser
Dr. Lama Issam Sakhnini

Deanship of Scientific Research
University of Bahrain
The Kingdom of Bahrain

2007

جامعة البحرين
LIBRARY
University of Bahrain

DECLARATION

I declare that this work is the result of my own investigation and that it has not already been accepted in substance for any degree, not is it being currently submitted for any degree.

Signed: ..... Date: ...5./11/...2007...

H. A. Al-Najjar

The thesis defense committee considers the Thesis titled:

"Measurement and Analysis of Radiofrequency Radiation Levels from Mobile Phone Base Stations in the Kingdom of Bahrain"

Submitted by Hasan Ali Abdulla Al-Najjar to the Deanship of Scientific Research satisfactory and acceptable for Master of Science degree in Environment and Sustainable Development.

Thesis Defense Committee:

Prof . Dr. Waheeb Essa Alnaser
Supervisor

Department of Physics
University of Bahrain

Dr. Lama Issam Sakhnini
Co-supervisor

Department of Physics
University of Bahrain

Prof Dr Paolo Vecchia
Member

National Institute of Health
Rome, ,Italy

Dr. Mohab Manjoud
Member

Department of Electrical Engineering
University of Bahrain

ACKNOWLEDGMENT

First of all I would like to thank Professor Waheeb Essa Alnaser, the supervisor, and Dr. Lama Sakhnini, the co-supervisor, for their guidance and help. I appreciate giving me their attention and valuable time during my work. This thesis couldn't be finished without their support and guidance.

Thanks also to Dr. Safwan Arekat, Chairman of Physics department for his technical advice and to the postgraduate committee at the Physics department for their good assessment of the MSc. proposal.

I would like also to thank my wife, Hana, for her support and patience during taking measurement in many sites around Bahrain.

I thank also my brother (Abdulla) and my brother in- law (Jasim) for their help in arrangement for long term measurements.

Finally, I would like to express my gratitude to all those people that in different ways have helped me with my work on this thesis.

ABSTRACT

A field survey was conducted to measure the level of Radio Frequency (RF) radiation emitted from the mobile phone's base stations to which the public may be exposed in Kingdom of Bahrain. The measured RF radiation levels were compared with the limits set by the International Commission of Non-Ionizing Radiation Protection (ICNIRP), and also with the national limits proposed by the Pollution Control Section of the Public Commission for the Protection of Marine Resources, Environment and Wildlife (PCPMREW) in Bahrain.

The sampling size was about 25% of exiting RF mobile phone's base stations (total of 300). The results show that RF radiation from the mobile phone's base stations are several orders of magnitude below both the limits of ICNIRP and PCPMREW. The highest recorded RF radiation level was in Sanabis town (3400 $\mu W/m^2$), in the GSM900 band. This value represents only 0.074% of the ICNIRP limit and represents only 3.4% of the PCPMREW limit. The average power density for all base station under survey was 577.6 $\mu W/m^2$, which is 0.013% of the ICNIRP limit (7964 times less) and 0.58% of the PCPMREW limit (173 times less). Among the five Governorates in Bahrain, the measured RF radiation had the highest average in the Capital (884 $\mu W/m^2$) and the lowest was in the Central Governorate (384 $\mu W/m^2$).

Furthermore, the measured magnetic field strength (**H**), in A/m, and the electric field strength (**E**), in V/m, from the mobile phone's base stations were compared with the limits set by ICNIRP and were found to be much lower and may be considered as safe. The highest **H** and **E** field value were recorded in Sanabis town, having magnitudes 3 mA/m and 1.133 V/m, respectively.

The Long-term RF radiation measurements (24 hour durations) showed some variations in RF radiation levels over this duration. In Addition, street mapping of the power density indicates that this radiation was shielded by urban structures and dissipated.

In conclusion, the measured RF radiation levels from the mobile phone base stations in the Kingdom of Bahrain are much lower than the limits set by ICNIRP and PCPMREW and not expected to cause health hazards, according to the current knowledge.

TABLE OF CONTENTS

Acknowledgment iii

Abstract iv

list of Tables vii

List of Figures viii

Abbreviations x

1. Introduction 1

1.1 Problem of the Thesis 1
1.2 Objectives and Significance 2
1.3 Previous Studies on Measurement of RF Radiation 3
1.4 Biological and Potential Health Effects of Radiofrequency Fields 8
1.4.1 Biological Effects 9
1.4.2. Health Effects 12

2. Theory 18

2.1 Radiofrequency Radiation, Definition and Characteristics 18
2.2 Units of Measuring Radiofrequency Radiation 20
2.3 Introduction of GSM Worldwide and in the Kingdom of Bahrain 22
2.4 Base Station Definition, Types and Structure 24
2.5 The Properties of the RF Beam from the Base Station 27

3. Guidelines for Limiting Exposure to Radiofrequency Radiation 33

3.1 Guidelines of International Commission of Non-Ionizing Radiation Protection (ICNIRP) 33
3.2 National Radiological Protection Board (NRPB) guidelines 36
3.3 The Institute of Electrical and Electronics Engineers (IEEE) standards 38
3.4 The Federal Communications Commission (FCC) Guidelines 39
3.5 The Australian Radiation Protection and Nuclear Safety Agency (ARPANSA) Guidelines 40
3.6 Health Canada 42
3.7 Italian Exposure Limits 44
3.8 Summary and Conclusion about Guidelines 45

4. Methodology 47

4.1 Equipments and Software 47
4.2 The Method Used in Choosing the Sample of Base Stations 48
4.3 Surveying Procedure 50

5. Results and Discussion 52

5.1 Environmental Measurements 52
5.2 Long Term (24 hours) Measurements of RF Radiation 79
5.3 Street Mapping of Power Density 85

6. Conclusions 86

References 93

Appendixes 98

The Abstract in Arabic Language 135

List of Tables

Table ***Page***

3.1: Basic restrictions adopted by ICNIRP for time varying electric and magnetic fields for frequencies up to 10 GHz. (ICNIRP, 1998). 35
3.2: Reference levels adopted by ICNIRP for general public exposure to time-varying electric and magnetic fields (unperturbed rms values) (ICNIRP, 1998) 36
3.3: NRPB basic restrictions on exposure in the frequency range 10 MHz to 10 GHz (NRPB, 1993 and IEGMP, 2000) 37
3.4: NRPB investigation levels for exposure at mobile telecommunications frequencies (NRPB, 1993 and IEGMP, 2000) 37
3.5: Basic restrictions for general public exposure according to IEEE. 38
3.6: Exposure limits recommended by IEEE for radiofrequencies for general public (uncontrolled environment) (IEEE, 1992 and (Levallois *et al.*, 1997). 38
3.7: FCC limits for whole-body and localized (partial-body) exposure (Cleveland and Ulcek, 1999) 40
3.8: Limits for Maximum Permissible Exposure (MPE) for general population (uncontrolled exposure) (FCC and LSGAC, 2000; Cleveland *et al.*, 1997) 40
3.9: Basic restrictions for whole-body average SAR and spatial peak SAR (ARPANSA, 2002) 41
3.10: Reference levels for time averaged exposure to rms electric and magnetic fields (unperturbed field) (ARPANSA, 2002). 42
3.11: SAR limits for persons not classed as RF and microwave exposed workers (including the general public) (Health Canada, 1999) 43
3.12: Exposure limits for persons not classed as RF and microwave exposed workers (including the general public) (Health Canada, 1999) 43
3.13: Restriction on RF exposure in Italy (Vecchia, 2007) 44
3.14: Comparison between different basic restrictions for general public exposure. 45
3.15: Comparison between different reference levels for general public exposure for frequency band of GSM 900 (925 – 960 MHz). 45
3.16: Comparison between different reference levels for general public exposure for frequency band of GSM 1800 (1805 – 1880 MHz). 46
3.17: Comparison between different reference levels for general public exposure for frequency band of UMTS (2110 – 2170 MHz) 46
4.1: Distribution of base stations at the five governorates in the Kingdom of Bahrain. 48
4.2: The numbers of base stations that were chosen for the measurements in the five governorates in the Kingdom of Bahrain. 50
5.1: The results of measuring RF radiation from 9 base stations in Al Muharraq Governorate. 54
5.2: The results of measuring RF radiation from 24 base stations in the Capital Governorate. 56
5.3: The results of measuring RF radiation from 16 base stations in the Northern Governorate. 60
5.4: The results of measuring RF radiation from 16 base stations in the Central Governorate. 63
5.5: The results of measuring RF radiation from 16 base stations in the Southern Governorate. 66

5.6: Maximum, Minimum, and Average for Al Muharraq Governorate results. 68
5.7: Maximum, Minimum, and Average for the Capital Governorate. 71
5.8: Maximum, Minimum, and Average for the Northern Governorate. 73
5.9: Maximum, Minimum, and Average for the Central Governorate. 75
5.10: Maximum, Minimum, and Average for the Southern Governorate. 77
5.11: Conversion between dBm and $\mu W/m^2$. 79

Note: The Tables in the appendixes is not included.

List of Figures

Figure ***Page***

2 .1: Electromagnetic Wave. 18
2.2: Radiofrequency Radiation Spectrum and sources (NRPB, 2004). 19
2.3: Public mobile spectrum assignments in Bahrain (<1900 MHz highlighted). 23
2.4: Current use of spectrum in the 1900 MHz – 2170 MHz band (TRA, 2006). 24
2.5: A base station contains a number of radio transmitters (trx) whose outputs are combined before being fed to an antenna and transmitted as radio waves. (Mann *et al.,* 2000). 26
2.6: Sector and dish antennae (HPA-2, 2006). 27
2.7: Radio signals used for communication between mobile phones and base stations (Mann *et al.,* 2000). 27
2.8: The shape of the beam formed by a typical antenna used with a macrocellular base station (HPA, 2006). 28
2.9: Antenna field regions for typical antennas 29
2.10: Schematic representation of the field strengths near a GSM 900 antenna with a radiated power of about 20 W. (Health Council of the Netherlands, 2000). 32
4.1: The spectrum analyser connected with the antenna via SMA adapter 47
4.2: The five governorates in the Kingdom of Bahrain 49
5.1: The map for the locations of the 9 base stations that was measured at Al Muharraq Governorate. 53
5.2: The map for the locations of the 16 base stations that was measured at the Capital Governorate. 55
5.3: The map for the locations of the 16 base stations that was measured at the Northern Governorate. 59
5.4: The map for the locations of the 16 base stations that was measured at the Central Governorate. 62
5.5: The map for the locations of the 16 base stations that was measured at the Southern Governorate. 65
5.6: Graph of Al Muharraq Governorate results. 68
5.7: Graph of maximum, minimum and average for the three network bands at Al Muharraq Governorate. 68

5.8: Graph of the Capital Governorate results..... 71
5.9: Graph of maximum, minimum and average for the three network bands at the Capital Governorate..... 71
5.10: Graph of the Northern Governorate results..... 73
5.11: Graph of maximum, minimum and average for the three network bands at the Northern Governorate..... 73
5.12: Graph of the Central Governorate results..... 75
5.13: Graph of maximum, minimum and average for the three network bands at the Central Governorate..... 75
5.14: Graph of the Southern Governorate results..... 77
5.15: Graph of maximum, minimum and average for the three network bands at the Southern Governorate..... 77
5.16: The comparison between the averages of the five Governorates for GSM900 band..... 78
5.17: Long term measurements of RF emission from the base station in Jidhafs-N13 (Northern Governorate)..... 80
5.18: Long term measurements of RF emission from the base station in Karbabad CM20 (Capital Governorate)..... 81
5.19: Long term measurements of RF emission from the base station in Samaheej (Al Muharraq Governorate)..... 82
5.20: Long term measurements of RF emission from the base station in Maqabah N5 (Northern Governorate)..... 83
5.21: Long term measurements of RF emission from the base station in Ras Al Rumman CM22 (Capital Governorate)..... 84
5.22: Street mapping of RF power density around base station in Kababad..... 85

Note: The Figures in the appendixes is not included.

Abbreviations

3G	Third Generation mobile-phone services
ANSI	American National Standards Institute
Batelco	Bahrain Telecommunications Company
CSTEE	Scientific Committee on Toxicity, Ecotoxicity and the Environment
DMP	digital mobile phones
EEG	Electroencephalogram
ELF	Extremely Low Frequency
EMF	Electro Magnetic Field
FCC	Federal Communications Commission
FDD	Frequency Division Duplex
GSM	Global System for Mobile Phone
ICNIRP	International Commission on Non-Ionizing Radiation Protection
IEEE	Institute of Electrical and Electronics Engineers
IEGMP	Independent Expert Group on Mobile Phones
MCMC	Malaysian Communication and Multimedia Commission
MINT	Malaysian Institute for Nuclear Technology Research
MPE	Maximum Permissible Exposure
MTC-Vodafone	Mobile Telecommunications Company
NBTB	neurobehavioral test battery
NRPB	National Radiological Protection Board
PCPMREW	The Public Commission for the Protection of Marine Resources, Environment and Wildlife in Bahrain.
REM	Rapid Eye Movement
RF	Radio-Frequency
rms	root mean square
RT	Reaction Time
SAR	Specific Absorption Rates
TDD	Time Division Duplex
TMT	Trail Making Task
TRA	Telecommunications Regulatory Authority
UMTS	Universal Mobile Telephone System
WHO	World Health Organization

CHAPTER 1

1. Introduction

1.1 Problem of the Thesis:

People are exposed to many sources of radiofrequency radiation. One of them is from the mobile phones and their base stations. Mobile phone is one of the fastest growing technologies worldwide. The use of mobile phones has increased considerably in recent years and has come to be seen as an essential means of communication in commerce and society. In the Kingdom of Bahrain, the number of total cellular mobile telephone subscribers increased from nearly 650 thousands on 31 December 2004 to nearly 899 thousands on 30 November 2006 (TRA, 2007). This means there is an increment of nearly 249 thousands (almost quarter of the total number of subscribers (899 thousands)) mobile phone users during one year and 11 months. The two mobile phone network operators in Bahrain will continue to install more and more base stations to meet the increasing demand of this service.

There have been concerns expressed about potential health risk associated with exposure to radiofrequency (RF) radiation from mobile phones and their base stations. Due to the growing body of evidence of possible biological and health hazards (raised by the media) of RF radiation from mobile phone's base stations many authorities set an exposure limits.

Unfortunately, there is no thorough study conducted in Bahrain to measure the levels of exposure of RF radiation from mobile phone's base stations in Bahrain with large number of sampling and cover the two operators, Batelco and MTC-Vodafone, for the three bands of mobile phone network GSM900, GSM1800 and the third Generation mobile-phone services (3G).

1.2 Objectives and Significance:

The main objective of this thesis is to conduct a survey for the RF radiation emitted by the mobile phone's base stations in the Kingdom of Bahrain. The survey will cover the base stations operated by the two mobile phone network operator in Bahrain and it will include the two bands of Global System for Mobile Phone ,GSM900 & GSM1800 (frequency bands 900 and 1800 MHz), and the third Generation mobile-phone services, 3G (frequency 2110 to 2170 MHz) which is based on the Universal Mobile Telephone System (UMTS).

The other subsidiary objectives of the thesis include the following:

- Analysing the data collected from the survey to know and specify the maximum, minimum and average for a group of base stations under survey in each governorate.
- Doing long-term (24 hours) measurements of the power density for selected base stations to understand how RF radiation varies during the day and also to specify the maximum, minimum and average for these base stations.
- Making comparisons with the limit for general public exposure specified in the relevant national and international standards.
- Mapping the level of RF radiation through streets and roads around selected base station.

The significant of the thesis arises from the fact that the RF radiation from mobile phone's base stations and their effects on environment is relatively a new issue compared to other environmental issues.

In response to growing public concern over possible biological and health effects from RF radiation of mobile phones and their base stations, it is important to conduct more researches and studies about RF radiation levels in our country. This study is independent and is the first non-governmental to survey the RF radiation levels in the vicinity of the mobile phone's base stations in the Kingdom of Bahrain.

This survey will be a comprehensive to include the three bands of mobile phone base stations (GSM900, GSM1800 and UMTS). It will give conception and description about the levels of RF radiation nearby base stations throughout the Kingdom of Bahrain. This will help the

community to become more aware and more understanding on the radiation exposure to RF from base stations.

Moreover, the results of this survey will indicate whether RF radiation from mobile phone's base stations exceeds the exposure limits set by our county or by other international authorities.

Our study could be a starting step towards future researches in this field in our country. We hope that our research will contribute in enhancing the national and international work on RF exposure limits and effects.

1.3 Previous Studies on Measurement of RF Radiation:

Many reports discussed the definition and characteristics of radiofrequency (RF) radiation and the units of measurements. These include NRPB (2003), Cleveland and Ulcek (1999), Means and Chan (2001), NRPB (2004), IEGMP (2000) and others.

Other studies reviewed the definition, types, structure of the base stations and the properties of their radiation (Mann *et al.*, 2000; Health Council of the Netherlands, 2000 and NRPB 2004).

A number of different national and international organizations have published guidelines for the protection of people from exposure to electromagnetic fields and radiation. For example, the International Commission on Non-Ionizing Radiation Protection (ICNIRP) had developed international guidelines on limits of exposure to non-ionising radiation. The most recent guidelines on the limiting exposure to electromagnetic fields were published in April 1998 by ICNIRP (ICNIRP, 1998). In UK, the national guidelines on exposure to RF radiation were drawn up by National Radiological Protection Board NRPB (NRPB, 1993). The Institute of Electrical and Electronics Engineers (IEEE's) recommendations on radiofrequencies were published in 1992 (IEEE, 1992). In 1996, the Federal Communications Commission (FCC) adopted updated guidelines for evaluating human exposure to RF fields from fixed transmitting antennas such as those used for cellular and mobile phones base stations. (Cleveland *et al.*, 1997).

There are many reviews on the potential health risks and biological effects of RF radiation made by many organizations such as ICNIRP (ICNIRP, 1998), NRPB 2004, Independent Expert Group on Mobile Phones (IEGMP, 2000), Health Council of the Netherlands (2000), Royal Society of Canada (1999) and United Nations Environment Programme/World Health Organization/International Radiation Protection Association (UNEP/WHO/IRPA, 1993).

Many studies and reports on different subjects related to RF radiation can be found in the web sites of the national and international organizations and commission such as The World Health Organization (WHO), The International Commission on Non-Ionizing Radiation Protection (ICNIRP), The National Institute of Environmental Health Sciences (NIEHS), Occupational Safety and Health Administration (USA), Health Protection Agency (UK) and The European Commission.

In the forthcoming sections we will summarize the previous surveys and studies conducted in different countries to measure the RF radiation levels.

In Bahrain, only three surveys and studies of non-ionising radiation have been carried out by the Pollution Control Section, Public Commission for the Protection of Marine Resources, Environment and Wildlife along with the international and national experts in the years 1995, 1999 and 2001(not published).

The first study was carried out during the period from 17 to 28 November 1995. The study investigated the significant sources of RF and EMF including telecommunication stations, electricity main stations, air traffic control facilities and broadcasting facilities. The survey results showed that only in the diathermy physiotherapy unit in Salmaniya Medical Complex (Operation on 27 MHz) the exposure to the electric field strengths was found to be more than 30 times the safety limits standards allowed by the American National Standards Institute and Institute of Electrical and Electronics Engineers. The other recorded values were insignificant and much lower than the international standards.

The second study was carried during the period from 4 to 28 December 1999. The RF and EMF sources investigated were: Telecommunications [Earth Station (Bu-Jarjorr Station), Al-Hamala Telecommunication Station - GSM Station - Radio and TV Stations - Air Port

Transmitting and Receiving Stations (Air to ground communication High Frequency (HF) - Very High Frequency (VHF) - Radar frequencies - Navigational Aids – Metrology - Weather Radar]. With respect to the GSM base stations, the study investigated the GSM900 band (945.200 MHz to 959.800 MHz). The results showed that the power densities in Salmaniya, Sanad and Jabal Al-Dakhan base stations vary from 2 to 4000 $\mu w/m^2$. This range does not exceed the ICNIRP limit (4.5 W/m^2), for the studied frequency.

The third study was carried out by a German Company (Rohde & Schwarz Cologne) in co-operation with the Public Commission for the Protection of Marine Resources, Environment and Wildlife and Batelco. It was conducted during the period from 22 to 31 July 2001. The Following RF and EMF sources were assessed and analysed:

- Electricity substations (32 units) and overhead power lines (6 units)
- Air traffic control and navigational aid facilities (13 units)
- Broadcasting and T.V stations (9 units)
- Telecommunication stations (40 GSM base stations).

Out of the 40 evaluated above locations, the highest level recorded was at Bukawara site in East Riffa. The limit specified by ICNIRP is at least 550 times greater than this level. The study also showed that mobile phone base stations and broadcasting towers produce weak RF and EMF radiation. The results clearly demonstrate that the RF and EMF values from GSM base stations, airport facilities and broadcast radio and television transmitters in Bahrain were at least several orders of magnitude below the limits set by ICNIRP.

In Kuwait, a survey on the radio frequency electromagnetic environment was carried out by Al-Otaibi and others (Al-Otaibi *et al.*, 1998). Measurements were made at 26 mobile phone base stations, chosen as a representative sample to include 14 school sites, 2 residential sites, 2 hospital sites, 3 ministerial building sites, 3 commercial sites and 1 typical stand-alone site. On all the selected sites measurements were made with a spectrum analyser to determine the emission level in the frequency bands used by the base station transmitters (frequency 917 to 960 MHz). The results indicated that total field strength, specifically due to the MTC base stations, found in public access areas, varied generally between 0.05 V/m (6.63 $\mu W/m^2$) and 1.13 V/m (3400 $\mu W/m^2$).

Australian Radiation Protection and Nuclear Safety Agency (ARPANSA) published a report which presents field survey measurements data and provides information on the levels of RF radiation to which members of the public may be exposed from these base stations (ARPANSA, 2000). The measured RF electromagnetic energy (EME) levels are compared with the maximum permitted limit for non-occupational exposure with respect to the Radiocommunications (Electromagnetic Radiation Human Exposure) Standard 1999 which specifies a maximum non-occupational exposure limit of 2 W/m^2 at relevant base station frequencies. The focus of the survey was on measuring the RF EME emission levels from the digital Global System for Mobile communication (GSM), but it involved investigating the EME levels from other sources, including the analog Advance Mobile Phone Systems (AMPS), VHF TV, UHF TV, AM radio, FM radio and Paging. The results clearly demonstrate that the RF EME emissions from GSM base stations are several orders of magnitude below the maximum permitted limit. The highest RF EME power flux density prediction, based on our measurements from GSM base stations, is 1780 $\mu W/m^2$ (at least 1,000 times less than the limit of 2 W/m^2). However, the average RF exposure level from GSM base stations is considerably less, 16 $\mu W/m^2$ (the 2 W/m^2 limit of power flux density is at least 100,000 times this average value) (ARPANSA, 2000).

Measurements of the fixed site environmental RF EME power flux density levels indicate that, relative to the maximum exposure limit permitted in the standard and after adjusting the exposure limit with respect to the frequency of the signal, the highest environmental RF exposure was FM radio (259 $\mu W/m^2$) – with the 2 W/m^2 limit of power flux density at least 7,000 times this value (ARPANSA, 2000).

Mobile phone base stations safety assessments carried out by Malaysian Institute for Nuclear Technology Research (MINT) in September 2003(Ali *et al.*, 2003). The results indicate that the radiation levels present on the ground, outside buildings around mobile phone's base stations, were very low and they varied according to location of the mobile phone's base stations site. The averaged radiation levels produced by the mobile phone's base stations were found to vary between 8×10^{-5} V/m (0.000017 $\mu W/m^2$) and 7.05×10^{-2} V/m (13.18 $\mu W/m^2$), which was 1.75×10^{-4}% and 0.15% of the most stringent (frequency 800MHz) exposure limit recommended by Malaysian Communication and Multimedia Commission (MCMC) and ICNIRP for members of the public. The total mobile signals present around the mobile phone

base stations were found to vary around 0.6 V/m (955 $\mu W/m^2$), i.e., 1.3% of the limit for public. The averaged total RF and microwave radiation (broadband) present around the mobile phone's base stations was obviously much higher and was found to vary between 0.8 V/m and 4.8 V/m (1700 $\mu W/m^2$ to 61 mW/m^2), which was 1.8% to 10.5% of the exposure limit recommended by MCMC and ICNIRP for members of the public. MINT's past experience indicates that these (broadband) radiation levels are comparable to the levels of the radiation normally present in urban environment away from any mobile phone base stations, which typically vary between 1 V/m to 4 V/m (2.7 mW/m^2 to 42 mW/m^2). The highest recorded radiation level was 5 V/m (66 mW/m^2), which was 10.9% of the permissible exposure limit for members of the public.

Another study in Malaysia was conducted on the measurement on radiation from mobile phone base stations at eight locations in International Islamic University of Malaysia, Gombak campus (Rafiqul Islam *et al.*, 2006). The measured electric field intensities, power densities and calculated specific absorption rate (SAR) values were compared with International Commission on Non-Ionizing Radiation Protection (ICNIRP) recommendations for safety guidelines. The results indicated that the microwave radiation for GSM900 and GSM1800 systems were approximately 34% lower than the recommended values in the campus. During measurement, it has been noticed that strong radiation was transmitting from Wireless LAN at 2.4 GHz bands, which is approximately 62% of the limit. The study recommended to investigate carefully the radiation from other sources before reaching to a decision that the campus is safe for it's population.

On the 8th and 9th of May 2002 representatives of the National Radiological Protection Board (NRPB) performed a radiofrequency electromagnetic field survey in the Cook ridge area of Leeds, England, in order to assess exposure to radio signals from transmitters mounted on a water tower, a lattice tower and a radio station tower (Fuller *et al.*, 2002). During this survey, the total exposures due to all radio signals from 30 MHz to 18000 MHz (18 GHz) were measured. This frequency range was chosen as it includes mobile phone's base station transmissions, which are at around 900 and 1800 MHz and super high frequency (SHF) transmissions from most of the large microwave dish antennas mounted on the towers. In addition, other major sources of radiofrequency electromagnetic fields in the environment such as broadcast radio and television transmissions are included in this range. Measurements

of power density were made at eight locations in the vicinity of the transmitter sites. Comparison of the measurements with the guidelines showed that the total exposure from radio signals measured between 30 MHz and 18 GHz ranged from 0.26 millionths (0.000026%) to 190 millionths (0.019%) of the NRPB investigation level and from 1.6 millionths (0.00016%) to 1400 millionths (0.14%) of the ICNIRP reference level for exposure of the general public. All the measured exposures are therefore many times below guideline levels and are not considered hazardous (Fuller *et al.*, 2002).

1.4 Biological and Potential Health Effects of Radiofrequency Fields:

The extensive studies and reports on RF radiation and its potential biological and adverse health effects has been reviewed by a number of authorities, including the Royal Society of Canada (1999), the Swedish Radiation Protection Authority (2005), Independent Expert Group on Mobile Phones (IEGMP, 2000), National Radiological Protection Board (NRPB, 2003 and 2004), Health Council of the Netherlands (2000) and United Nations Environment Programme/World Health Organization/International Radiation Protection Association (UNEP/WHO/IRPA, 1993). This section provides brief summary on some research results on the biological and potential health risks of RF radiation. However, more details can be found in previous organizations reports and other studies and reviews.

In analysing the available data, it is important to distinguish between biological effects and health effects. Biological effects are measurable changes in biological systems that may or may not be associated with adverse health effects. A biological effect is considered to be a physiological effect that is induced by an external cause and that falls within the natural limits between which processes and functions of a living organism can vary without this leading to adverse health effects. A health effect is the negative consequence for the health of an organism of the inability to sufficiently compensate physiological effects. If an effect has been demonstrated in experimental research on an isolated biological system, for instance an effect on cultured cells, this does not necessarily imply that there will be adverse effects for the health of the organism as a whole.

1.4.1 Biological Effects:

Calcium efflux:

Considerable work has been done on the effects of RF fields on calcium efflux in brain tissue and reviewed by UNEP/WHO/IRPA (1993), Royal Society of Canada (1999) and (IEGMP, 2000). UNEP/WHO/IRPA (1993) reviewed many studies about calcium efflux and many of them reported increases in calcium efflux in isolated tissues (in vitro). For example Bawin (UNEP/WHO/IRPA, 1993) reported that exposure to 147 MHz fields at intensities too low to cause heating lead to an increase in the efflux of calcium from chick brain, but only if the field was amplitude modulated at 16 Hz. The RF carrier frequency alone had no obvious effect. This observation was confirmed by Blackman who used a number of different frequencies of amplitude modulation (3–30 Hz) and found that the effect was maximal at 16 Hz (UNEP/WHO/IRPA, 1993).

A number of subsequent studies in other laboratories had failed to detect an increase in calcium efflux from brain explants *in vitro* (UNEP/WHO/IRPA, 1993), but they generally used different conditions of stimulation.

According to IEGMP (IEGMP, 2000), there have been only two attempts to determine if such efflux of calcium occurs *in vivo*. The first was Adey who exposed cats to 16 Hz amplitude-modulated 450 MHz fields (SAR of 0.29 W/kg) and reported changes in calcium ion-exchange in the cerebral cortex. The second was Merritt who did not find such an effect in the brain of anaesthetised rats (IEGMP, 2000).

Blood-brain Barrier:

The blood–brain barrier serves to protect the brain from potentially harmful compounds and helps to regulate and control the fluid environment of the brain cells (NRPB, 2004).

Several studies have shown that exposure to RF radiation below the exposure limits in CANADA does increase blood-brain permeability (Royal Society of Canada, 1999). However, not all studies have demonstrated this effect. These inconsistencies may indicate that effects at low-level RF exposure are not significant, or that the changes in permeability may be related to the specific RF frequency or to the Extremely Low Frequency (ELF) modulation of the RF carrier frequency (Royal Society of Canada, 1999).

The Independent Expert Group on Mobile Phones (IEGMP) stated that "The available evidence for an effect of RF exposure on the blood–brain barrier is inconsistent and contradictory. Recent, well-conducted studies have not reported any effects." (IEGMP, 2000). The Swedish Radiation Protection Authority concluded that "Most of the recent results of studies aimed at replicating earlier positive work have been negative at low SAR levels". Further studies on the permeability of the blood-brain-barrier or on damaged (darkly-staining) neurons are ongoing and should give more information on the issue. On balance, the evidence that exposure to RF fields alters the blood-brain-barrier is weak." (Swedish Radiation Protection Authority, 2005).

Health Council of the Netherlands reported that a number of studies from the 1970s and 1980s seem to indicate that exposure to electromagnetic fields affects the permeability of the blood-brain barrier. However, recent research has been unable to reproduce these effects. The Electromagnetic Fields Committee of the Health Council of the Netherlands is of the opinion that there are no scientific grounds to assume the existence of such effects (Health Council of the Netherlands, 2002).

Ornithine Decarboxylase (ODC) Activity:

Ornithine Decarboxylase (ODC) is a key enzyme required for cells to grow and divide. Its activation is related to cell proliferation and most tumour promoters increase the activity of ODC. In this regard, ODC activity has been used in cells to test for tumour promoting agents (NRPB, 2003). Increase in ODC activity have been observed in experiments using RF fields in the frequency range of standard wireless telecommunications devices at exposure levels below those recommended in Canada (Royal Society of Canada, 1999). This increased activity occurs only when the amplitude of the radiofrequency field is modulated by ELF. Pulsed digital telephone fields with a low frequency component also are capable of increasing ODC activity. ODC activity has been shown to increase with increasing RF field strength. The panel noted that while nearly all factors capable of causing cancer lead to elevated ODC activity, not all stimuli capable of increasing ODC activity promote cancer (Royal Society of Canada, 1999). IEGMP concluded that Pulse-modulated RF fields from mobile phones may cause a slight increase in ODC levels and activity, at non-thermal levels. However, it is very unlikely that these small changes could - on their own - have a tumor promoting effect. It is

also unlikely that such effects act synergistically with other environmental hazards and contribute to tumor promotion (IEGMP, 2000).

Zmirou (Zmirou, 2001) reported that the activity of the intracellular enzyme ODC was increased in several experiments with amplitude-modulated fields, but not in the case of frequency modulation or no modulation at all. In view of the possible role of ODC in the promotion or progression of cancer, this could point to the possibility of some epigenetic mechanism of carcinogenesis but this work needs to be replicated.

Melatonin:

Melatonin is a hormone secreted by the pineal gland, which controls our diurnal rhythm (day–night cycle) (IEGMP, 2000). Although few studies have been conducted, they do not suggest that exposure to RF fields affects pineal function or melatonin production. Relevance to the use of mobile phones could, in any case, be assessed only through laboratory studies of people because of species differences in the pattern of circadian rhythms. It must also be emphasized that the hypothalamus and pineal gland are much further from the surface of the head in people than in animals. Therefore, even if there was an effect on melatonin production in animals resulting from a direct interaction of fields within the brain, it would be much less likely to occur in people (IEGMP, 2000).

According to Royal Society of Canada, the effect of extremely low frequency electric and magnetic fields on melatonin has been widely studied in animals and humans. It has been hypothesized that ELF fields could alter human disease processes through changes in melatonin. Because melatonin levels are strongly affected by exposure to light, and may be affected by exposure to ELF fields, it is reasonable to consider whether melatonin might be affected by exposure to RF fields. However, there has been very little research on the effects of RF on melatonin, and the few existing studies do not provide clear information about such effects (Royal Society of Canada, 1999).

Cell proliferation:

According to the Royal Society of Canada (1999), various findings have been reported on the effects of RF on cell proliferation. There is evidence that cell proliferation (specifically LN71

glioma cells) may be increased through exposure to high intensity RF fields under rigid thermal control conditions. Alterations in cellcycle kinetics under similar exposure conditions have been observed using Chinese hamster ovary cells. However, other studies have not demonstrated increased cell growth. A decrease in cell growth was seen only after 30 minutes cell exposure or less. At low intensity non-thermal levels RF fields do not appear to alter cellular proliferation rates. On the other hand, after reviewed several studies about cell proliferation, IEGMP concluded that they do not demonstrate convincing, consistent changes in cell proliferation under conditions that mimic emissions from mobile phones or base stations (IEGMP, 2000).

1.4.2. Health Effects:

Cognitive functions/neurophysiology:
Several studies and reports were done about RF exposure and cognitive functions. Recent results have not clarified the picture. Swedish radiation protection authority reported that changes in cognitive functions have been reported but the results are inconsistent and no single clear effect on cognitive function can be identified (Swedish radiation protection authority, 2004).

Preece (Preece, 1999) concluded that "there was evidence of an increase in responsiveness, strongly in the analogue and less in the digital simulation, in choice reaction time. This could be associated with an effect on the angular gyrus that acts as an interface between the visual and speech centres and which lies directly under and on the same side as the antenna. Such an effect could be consistent with mild localized heating, or possibly a non-thermal response, which is nevertheless power-dependent."

A cross-sectional study was conducted on (85) inhabitants living nearby the first mobile phone's station antenna in Menoufiya governorate, Egypt- 37 are living in a building under the station antenna while 48 opposite the station- (Abdel-Rassoul *et al.*, 2006). A control group (80) participants were matched with the exposed for age, sex, occupation and educational level. All participants completed a structured questionnaire containing: personal, educational and medical histories; general and neurological examinations; neurobehavioral test battery (NBTB) [involving tests for visuomotor speed, problem solving, attention and memory]; in addition to Eysenck personality questionnaire (EPQ). *The researchers concluded*

that inhabitants living nearby mobile phone's base stations are at risk for developing neuropsychiatric problems and some changes in the performance of neurobehavioral functions either by facilitation or inhibition.

Keetley and others (Keetley *et al.*, 2006).compared the performance of 120 volunteers on 8 neuropsychological tests during real or sham exposure to digital mobile phones (DMP) set to maximum permissible radiofrequency power output. *The results provided statistical evidence of a cognitive difference in performance between the real and sham field DMP exposure conditions. The negative effects of DMP exposure on Reaction Time (RT) performance indicate that the more basic functions were adversely affected by exposure.* In contrast, the improved RT for the Trail Making Task (TMT) working memory task suggests that *DMP exposure has a positive effect on tasks requiring higher level cortical functioning, such as working memory.* The implications of this study can only be directed towards the effects of short-term exposure of DMP RF radiation on cognition. Further longitudinal research is required to determine the effects that long-term use of DMPs (years) may have on health and cognition.

Scientific Committee on Toxicity, Ecotoxicity and the Environment (CSTEE, 2001) reported that relevance of experimental studies to man is uncertain because of interspecies differences in the perception of intense pulsed RF fields. *Studies on the acute effects of mobile phones on human volunteers have shown some neurobehavioral changes (such so-called neurobehavioral effects are mostly reporting of subjective malaise), the mechanism of which might include a localised heating effect.*

The Royal Society of Canada study (Royal Society of Canada, 1999) concluded that some studies suggest that some aspects of cognitive functions and measures of brain physiology may be affected while others do not. These include changes in memory tasks, response patterns, normal sleeping Electroencephalogram (EEG) patterns, and other brain functional changes although a few studies have demonstrated improved cognitive functions in volunteers exposed to RF radiation in the frequency range of mobile phones. Subjective symptoms such as dizziness, disorientation, nausea, headache, and other unpleasant feelings might be a direct result of RF fields although such symptoms are very general and may have many other causes.

EEG and sleep:

Literature on the effects of RF and EMFs on sleep was reviewed by many researchers and organizations. Mann and Roschke (Mann and Roschke, 2004), reported that the epidemiological studies provide no evidence that sleep disturbances are a relevant complaint under exposure to high-frequency EMF. They stated that "Recent sleep laboratory studies have revealed a number of slight effects. Despite their heterogeneity, there seems to be some consistency regarding a slight sleep-promoting effect and an increase of the alpha power of the sleep EEG induced by high-frequency EMFs. However, for both the epidemiological and sleep laboratory studies, the database concerning sleep is up to now very limited".

According to Swedish Radiation Protection Authority, an Australian group in 2005 has reported minor effects on REM sleep (dream phase) following exposure of volunteers to mobile phone signals at moderate level for 30 min. (Swedish Radiation Protection Authority, 2005). It had reported that recent investigations on humans and animals have not added clear evidence of alteration of EEG or sleep and the relevance of minor alterations on EEG and sleep on health is not significant. It concluded that there may be alterations of sleep caused by exposure, but the data are still inconsistent. Moreover, there is no known effect on health attributable to these low-amplitude alterations of sleep (Swedish Radiation Protection Authority, 2005).

IEGMP concluded that most of the work on neurotransmitter systems has used high power densities and has probably revealed thermoregulatory or other responses to temperature change. However, in view of the essential role of neurotransmitters in brain function and the involvement of specific transmitter systems in the regulation of emotion, memory, sleep, etc, this area deserves further investigation, including the assessment of these functions in human subjects (IEGMP, 2000). Also IEGMP reported that studies of the EEG in animals have generally not employed conditions that are directly relevant to mobile phone technology, and the results have been mixed. However, some experiments have produced evidence of non-thermal effects from RF fields on brain activity. Experiments on human volunteers, with exposure conditions similar to those experienced in using a mobile phone, have been more informative (IEGMP, 2000).

The Health Council of the Netherlands concluded that the data relating to effects on the brain during sleep are ambiguous. Although effects on the EEG pattern have been observed, this was during the non-REM phases in the case of the studies conducted in Mainz, while the effects in the studies in Zürich conversely occurred during the REM phases. *No correlation with increasing field strength was found.* The time-lag effect found in the study by Huber (Health Council of the Netherlands, 2002) is striking. This should be investigated further. The Health Council of the Netherlands also concludes that on the basis of these findings, there is no reason to suppose that the effects lead to health problems. It points out that similar effects have also been found as a result of caffeine consumption and natural hormonal fluctuations. However, all the studies have been conducted with young healthy volunteers. It should be determined whether people with existing sleep-related or other disorders might be more sensitive (Health Council of the Netherlands, 2002).

Genotoxicity:

Possible genotoxic effects of RF radiation have been of considerable interest because of their potential importance for cancer risk assessment. According to Scientific Committee on Toxicity, Ecotoxicity and the Environment (CSTEE), an overview of *in vitro* genotoxicity data, subjected to a weight-of-evidence evaluation concluded that there are no strong indications that electromagnetic fields between 30 MHz and 300 GHz cause DNA damage. Where effects were found, they were attributable to hyperthermia. Despite minor inconsistencies in the literature, it is concluded that, *in vivo* and *in vitro* experiments on the induction of *micronuclei*, SCE or chromosomal aberrations did not detect any effect. Cell transformation assays of radiofrequency field exposure are difficult to interpret because of technical difficulties. There have been reports of DNA fragmentation and on effects on nucleic acid synthesis, which could be relevant to malignancy, but these have not been confirmed independently and are subject to much controversy. The possible interaction between electromagnetic fields and physical or chemical mutagenic or carcinogenic agents represents an interesting hypothesis, which has not been yet sufficiently investigated (CSTEE, 2001).

Swedish Radiation Protection Authority concluded that it is generally *accepted that RF radiation lacks sufficient energy to damage DNA directly, but experimental studies are useful in investigating the possibility of increased DNA damage by indirect mechanisms*. The effects

of RF fields on many different genotoxicity endpoints have been evaluated both *in vitro* and *in vivo, and most of the studies have reported no effects* (Swedish Radiation Protection Authority, 2005). On balance, the recent studies reviewed do not provide sufficient evidence to conclude that RF fields are genotoxic (Swedish Radiation Protection Authority, 2005).

IEGMP concluded that several different assays of genotoxicity have failed to produce clear evidence that RF radiation is genotoxic at non-thermal levels. The most consistent results come from observations of micronucleus formation, but these are not simple to interpret and have uncertain implications for health (IEGMP, 2000).

Experimental carcinogenesis:

The possible carcinogenicity of RF radiation has been investigated in a number of experimental systems. According to CSTEE the Experimental carcinogenesis results have been essentially negative and the Original observations of a possible promoting effect on mammary carcinogenesis in mice were not confirmed in subsequent studies. An interesting observation is that of Repacholi (Repacholi, 1997) who induced a two-fold increase in lymphoma incidence in a strain of lymphoma-prone transgenic mice (E mu-Pim1) following exposure (1 hour daily for up to 18 months) to plane-wave fields of 900 MHz with a pulse repetition frequency of 217 Hz and a pulse width of 0.6 ms. *As yet, the open literature has not reported any replication of this finding. It is therefore concluded that it provides inadequate evidence of experimental carcinogenicity (*CSTEE, 2001).

Reviewers evaluating possible links between RF exposure and excess risk of cancer have concluded that there is no clear evidence for such a link. According to Repacholi (Repacholi, 1997) the United Kingdom NRPB Advisory Group on Non-ionising Radiation concluded that *there is no firm quantitative evidence of a carcinogenic hazard from electromagnetic field exposures for the general public and workers in the electrical, electronics, and telecommunications industries*. Studies published since this review was completed have not shed any further light on the possibility that RF exposure poses a carcinogenic risk. After a detailed review of the scientific literature, the International Commission on Non-Ionizing Radiation Protection (ICNIRP) concluded that "*there is no substantive evidence that adverse health effects, including cancer, can occur in people exposed to levels at or below the limits*

on whole body average SAR recommended by INIRC or, at or below the ICNIRP limits for localised SAR...." Few studies have been conducted that specifically address the issue of cancer and RF exposure (Repacholi, 1997). More multidisciplinary focused studies are needed to address this (Repacholi, 1997).

Dasenbrock (Dasenbrock, 2005).concluded that the animal cancer studies reviewed and published until now did not show a significant tumour-promoting or co-carcinogenic effect due to mobile phone-relevant RF radiation. The only exception was Repacholi's study of 1997. Most of these studies, however, lack on several of the following points: (a) one exposure level (''dose'') only, (b) no justification for the selected RF dose(s), (c) inaccurate dosimetry, e.g., for growing animals, (d) no justification for the group size chosen and missing power analysis, (e) missing data on microbiological/ parasitological animal health, (f) no standardized tumour nomenclature and/or no peer review or PWG on histopathological diagnoses and (g) the 7,12-dimethylbenz[a]anthracene (DMBA) mammary tumour model did not give reproducible tumour responses.

CHAPTER 2

2. Theory

In the following, the theoretical frame work of the radiofrequency radiation and mobile phone base stations will be explained and discussed.

2.1 Radiofrequency Radiation, Definition and Characteristics:

Radiofrequency (RF) radiation is a part of electromagnetic spectrum and can be defined as "Electromagnetic radiation used for telecommunications and found in the electromagnetic spectrum at longer wavelengths than infrared radiation." (IEGMP, 2000).

Electromagnetic radiation can best be described as waves of electric (**E**) and magnetic (**B**) energy moving perpendicular together (i.e., radiating) through space, as illustrated in Figure 2.1. These waves are generated by the movement of electrical charges such as in a conductive metal object or antenna. For example, the alternating movement of charge (i.e., the "current") in an antenna used by a radio or television broadcast station or in a mobile phone base station antenna generates electromagnetic waves that radiate away from the "transmit" antenna and are then intercepted by a "receive" antenna such as a rooftop TV antenna, car radio antenna or an antenna integrated into a hand-held device such as a mobile phone.

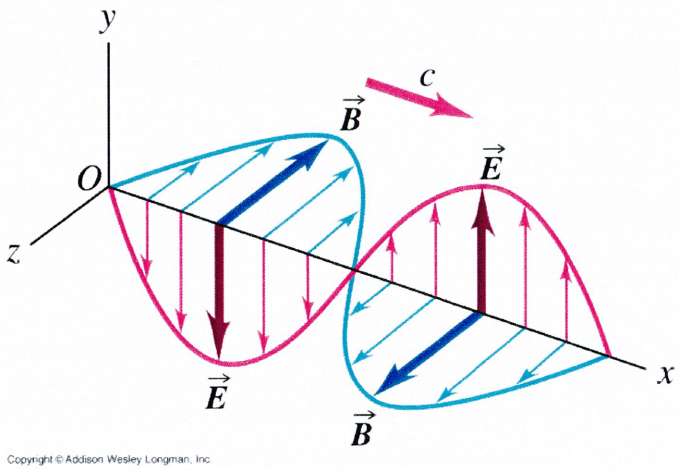


Figure 2 .1: Electromagnetic wave.

The electromagnetic waves, and therefore RF radiation, travel through space at speed of light ($c = 3\times10^8$ m/s) and characterized by its wavelength (λ) and frequency (f). The wavelength (λ) is defined as "the distance covered by one complete wave cycle" where as the frequency (f) is "the number of waves passing a given point in one second."

The wavelength (λ) and the frequency (f) of an electromagnetic wave are inversely related by the following equation:

$$c = \lambda \times f \qquad (1)$$

Where λ is a distance and so its units are cm, m or km. On the other hand f is measured in units of Hertz (Hz), kHz (=1000 Hz), MHz ($=10^6$ Hz) or GHz ($=10^9$Hz).

The frequency range of RF radiation is between 3 kHz and 300 GHz (Cleveland and Ulcek, 1999; NRPB, 2003). This range includes a variety of RF sources in addition to those used for telecommunications. These are shown in Figure 2.2.

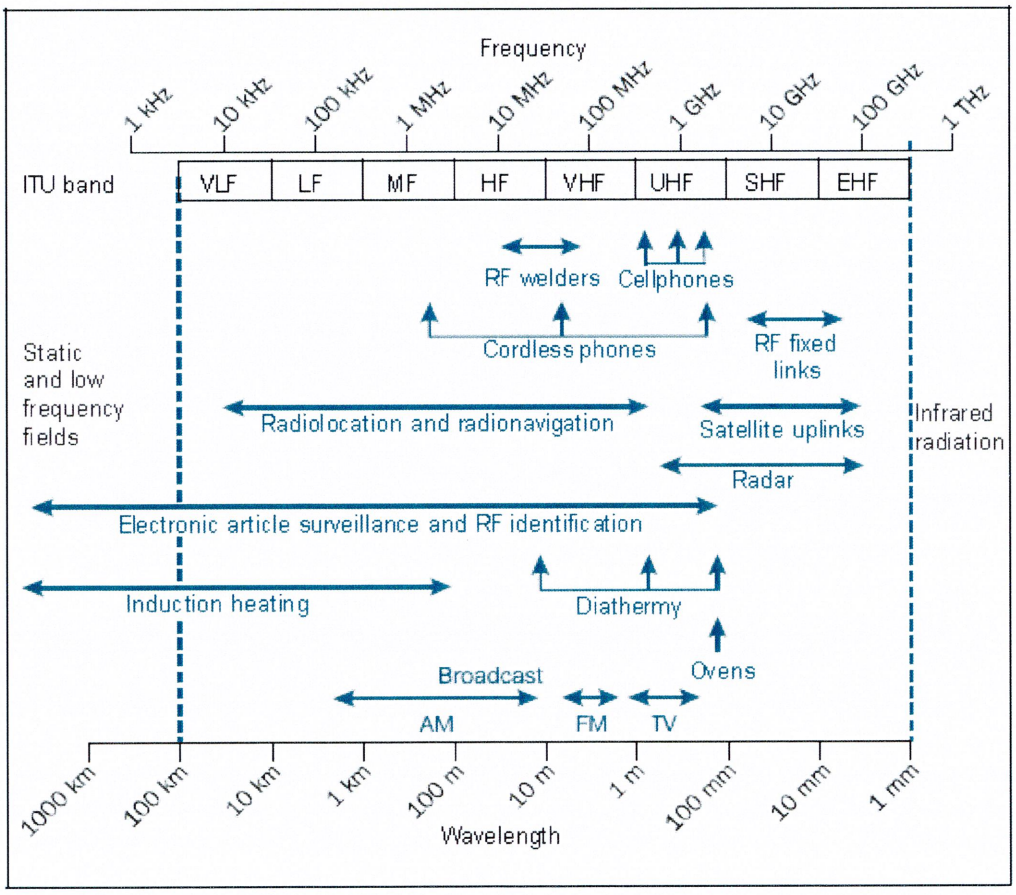


Figure 2.2: Radiofrequency Radiation Spectrum and sources (NRPB, 2004).

2.2 Units of Measuring Radiofrequency Radiation:

An RF electromagnetic wave or RF "field" has both an electric and a magnetic component (electric field and magnetic field), and it is often convenient to express the intensity of the RF radiation at a given location in terms of units specific for each component. The unit "Volts per meter" (V/m) is used to measure the strength of the electric (**E**) field (electric "field strength"). A magnetic field can be specified in two ways—as magnetic flux density, **B**, expressed in tesla (T), or as magnetic field strength, **H**, expressed in ampere per meter (A/m). The two quantities are related by the expression:

$$\mathbf{B} = \mu \times \mathbf{H} \qquad (2)$$

where μ is the constant of proportionality (the magnetic permeability); in a vacuum and in air, as well as in non-magnetic (including biological) materials, μ has the value $4\pi \times 10^{-7}$ when expressed in henry per meter (H/m). Thus, in describing a magnetic field for protection purposes, only one of the quantities **B** or **H** needs to be specified.

Another commonly used unit for characterizing an RF electromagnetic field is "power density." Power density is defined as power per unit area. For example, power density can be expressed in terms of milli Watts per square centimeter (mW/cm^2) or microwatts per square centimeter ($\mu W/cm^2$). One mW equals 0.001 Watt of power, and one μW equals 1×10^{-6} Watt.

Power density is most accurately used when the point of measurement is far enough away from the RF emitter to be located in what is commonly referred to as the "far-field" zone of the radiation source, *e.g., more than several wavelengths distance from a typical RF source.* In the far field, the electric and magnetic fields are related to each other in a known way, and it is only necessary to measure one of these quantities in order to determine the other quantity or the power density. In the far-field region, the plane-wave model is a good approximation of the electromagnetic field propagation. The characteristics of a plane wave are:

- The wave fronts have a planar geometry;
- The **E** and **H** vectors and the direction of propagation are mutually perpendicular;
- The phase of the **E** and **H** fields is the same, and the quotient of the amplitude of **E/H** is constant throughout space. In free space, the ratio of their amplitudes **E/H** = 377 ohm, which is the characteristic impedance of free space;

- Power density, **S**, i.e., the power per unit area normal to the direction of propagation, is related to the electric and magnetic fields by the expression:

$$\mathbf{S} = \mathbf{E} \times \mathbf{H} = \mathbf{E}^2 / 377 = 377 \times \mathbf{H}^2 \qquad (3)$$

In closer proximity to an antenna, i.e., in the "near-field" zone, the physical relationships between the electric and magnetic components of the field are usually complex. In this case, it is necessary to determine both the electric and magnetic field strengths to fully characterize the RF environment (Cleveland and Ulcek, 1999).

Since the area of a sphere surrounding a source increases as the square of its radius, then in an ideal case (in the absence of any nearby objects including the ground) the power density falls off as $1/(\text{distance})^2$, the inverse square law.

The quantity used to measure how much RF energy is actually absorbed in a body is called the "Specific Absorption Rate" or "SAR." It is usually expressed in units of Watts per kilogram (W/kg) or milliwatts per gram (mW/g). In the case of exposure of the whole body, a standing human adult can absorb RF energy at a maximum rate when the frequency of the RF radiation is in the range of about 80 and 100 MHz. This means that the "whole-body" SAR is at a maximum under these conditions. Because of this "resonance" phenomenon, RF safety standards are generally most restrictive for these frequencies (Classic, 2007). For exposure of parts of the body, such as the exposure from hand-held mobile phones, SAR is also used to measure absorption of RF energy.

SAR compliance for low power transmitters are evaluated with electric field measurements inside homogeneous tissue models or computer modeling techniques using anatomically equivalent tissue models. In either case, SAR is determined according to this equation (David and Kwok, 2001).

$$SAR = \frac{|E|^2 \sigma}{\rho} \qquad (4)$$

where $|E|$ is the magnitude of the measured or computed root mean square (rms) electric field, σ is the conductivity (Siemens per meter (S/m)) and ρ is the mass density (kg/m^3) of the tissue-equivalent media. SAR can also be determined from temperature rises due to RF energy absorption in tissue media according to the equation (Means and Chan, 2001):

$$SAR = C\frac{\delta T}{\delta t} \qquad (5)$$

where C is the specific heat of tissue, δT is the temperature rise and δt is the exposure duration. However, in order to use temperature techniques, relatively high power is required to expose the tissue over a very short duration to avoid thermal diffusion errors. Therefore, temperature methods are typically not applicable for evaluating low power transmitters for SAR (Means and Chan, 2001).

2.3 Introduction of GSM Worldwide and in the Kingdom of Bahrain:

During the early 1980s, analog cellular telephone systems were experiencing rapid growth in Europe. Each country developed its own system, which was incompatible with everyone else's in equipment and operation. This was an undesirable situation, because the mobile equipment was limited to operation within national boundaries, and there was also a very limited market for each type of equipment, so economies of scale and the subsequent savings could not be realized. The Europeans realized this early. In 1982 the Conference of European Posts and Telegraphs (CEPT) formed a study group called the Groupe Spécial Mobile (GSM) to study and develop a pan-European public land mobile system (Scourias, 1997).

In 1989, GSM responsibility was transferred to the European Telecommunication Standards Institute (ETSI), and phase I of the GSM specifications were published in 1990. Commercial service was started in mid-1991, and by 1993 there were 36 GSM networks in 22 countries (Scourias, 1997). Although standardized in Europe, GSM is not only a European standard. Over 200 GSM networks (including DCS1800 and PCS1900) are operational in 110 countries around the world. In the beginning of 1994, there were 1.3 million subscribers worldwide, which had grown to more than 55 million by October 1997 (Scourias, 1997). With North America making a delayed entry into the GSM field with a derivative of GSM called PCS1900, GSM systems exist on every continent, and the acronym GSM now aptly stands for Global System for Mobile communications.

In 1995, the digital Global System for Mobile Telecommunications (GSM) network was launched in the Kingdom of Bahrain (Batelco, 2006). At this time, there were only one operator (Batelco) and the number of mobile phone users was considerably less than that

today. For these reasons fewer base stations were required to fulfill operational considerations with consequential lesser impact on the environment. After four years, in 1999, Batelco's mobile phone customers reach 100,000 (Batelco, 2006).

The second operator for GSM (MTC-Vodafone) was launched in 2003 with the first third generation networks (3G) (MTC, 2006). The number of base station sites began to increase rapidly due to increasing usage of mobile phones to about 899 thousands on 30 November 2006 (TRA, 2007).

While in principle the GSM system can be implemented in any frequency band, there are far fewer bands where GSM handsets are available. There are five frequency bands used by GSM: GSM 900, GSM 1800, GSM 850, GSM 1900 and GSM 400. Of these, GSM 900 and GSM 1800 are used in most parts of the world, with GSM 850 and GSM 1900 limited mainly to the Americas. GSM 400 has experienced very little deployment so far.

The current allocation of the spectrum for GSM in the Kingdom of Bahrain follows the standard GSM 900 and GSM 1800 frequencies allocation (see Figure 2.3) (TRA, 2006). Both the standard GSM 900 and extended GSM 900 frequency bands have been allocated to public mobile in Bahrain. Public mobile spectrum is currently split between Batelco and MTC-Vodafone. The Extended GSM spectrum has only been assigned to MTC-Vodafone.

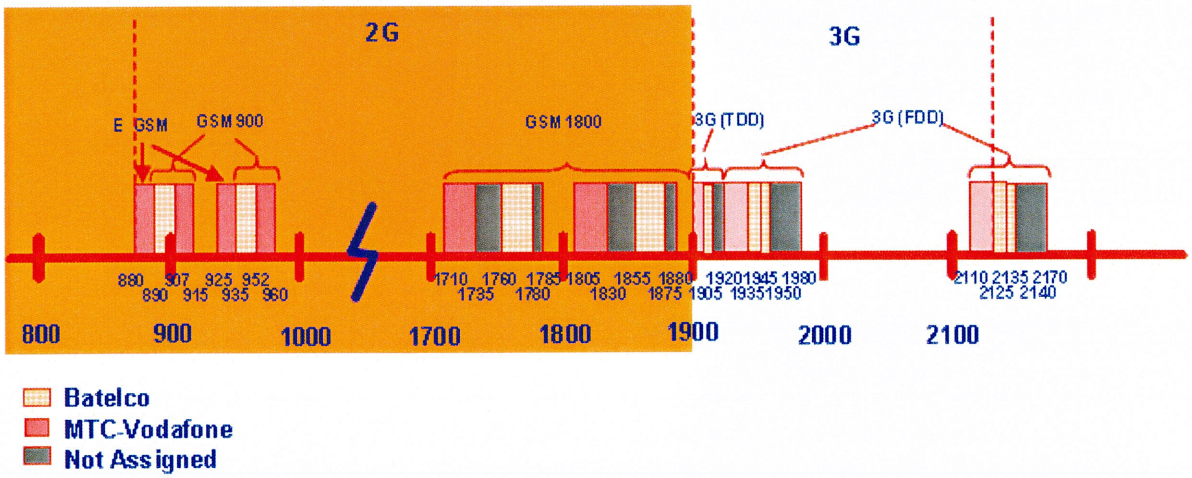


Figure 2.3: Public mobile spectrum assignments in Bahrain (<1900 MHz highlighted).

MTC-Vodafone has been assigned 3G frequency spectrum (as part of the award of the second mobile licence). It was assigned 1×5 MHz within the 1900–1920 MHz TDD band, and 2×15

MHz within the 1920–1980 MHz / 2110–2170 MHz FDD band. This 3G spectrum was granted to MTC-Vodafone in 2003. In addition, Batelco has the right to part of the 3G spectrum. 1×5 MHz in the TDD band and 2×15 MHz in the FDD band have been reserved for Batelco. It should be noted that spectrum between 1427 MHz and 2700 MHz is used in parts by the government, potentially conflicting with 3G users. However, the government has been consulted on this matter, and it has been concluded that expected government usage of the 3G spectrum will not be at a level which would impede future 3G assignment (TRA, 2006). There is an additional 52.5 MHz of free spectrum in this band (10 MHz + 22.5 MHz + 20 MHz), as shown in Figure 2.4.

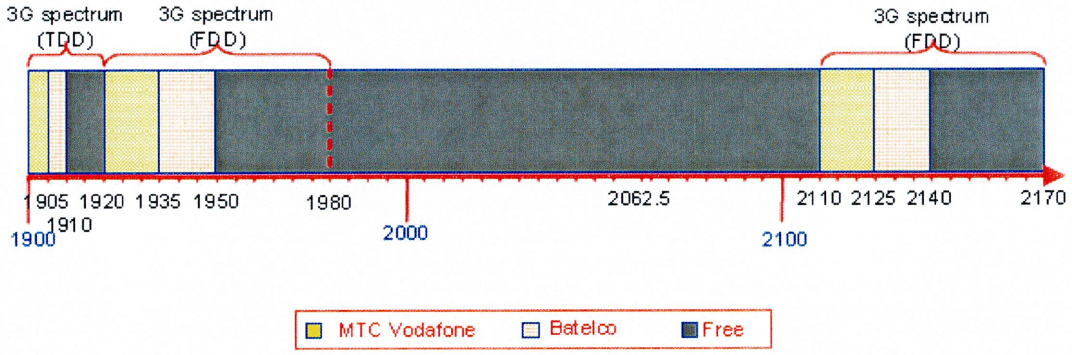


Figure 2.4: Current use of spectrum in the 1900 MHz – 2170 MHz band (TRA, 2006).

2.4 Base Station Definition, Types and Structure:

Mobile phone base stations are radio transmitters with antennas mounted on either free-standing masts or on building (HPA, 2006). Base station and mobile phone handset are the two communicating elements that form a mobile phone network. The mobile phone handset transmits radio waves to the base station, and these carry the voice of the phone user. Similarly, the base station transmits radio waves to the mobile phone and these carry the voice of the person the phone user is listening to. The base station passes the signals to and from the phone network.

There are many different types of base stations used by operators and it is not always easy to firmly categorise them as macro-cell, micro-cell or pico-cell. Categorizations tend to be based

on the purpose of the site rather than in terms of technical constraints such as radiated powers or antenna heights (HPA, 2006).

A macro-cell provides the main coverage in a mobile network. The antennas for macro-cells are mounted on ground-based masts, rooftops and other existing structures. They must be positioned at a height that is not obstructed by surrounding buildings and terrain. Macro-cell base stations have a typical power output of tens of Watts.

Micro-cells provide infill radio coverage and additional capacity where there are high numbers of users within macro-cells. The antennas for micro-cells are mounted at street level, typically on the external walls of existing structures, lamp posts and other street furniture. The antennas are smaller than macro-cell antennas and, when mounted on existing structures, often blend in with building features to minimize visual impact. Typically, micro-cells provide radio coverage across smaller distances and are placed 300m-1000m apart. They have lower outputs than macro-cells, usually a few Watts.

A pico-cell provides more localized coverage than a micro-cell. They are normally found inside buildings where coverage is poor or where there are a high number of users, such as airport terminals, train stations or shopping centres. They also have lower outputs than macro-cell and occupancy is generally low (NRPB, 2004).

The base station consists of many parts that combined. These parts are plants room, mast, antennae and cables.

- *Plant room (base station):* When discussing base stations, it is important to be clear that, in strictly engineering terms, it is the electronic equipment contained in the plant room, shown in Figure 2.5, which is the base station. Nevertheless, it has become common practice to describe the complete installation, including antennas and mast, as the base station (Mann *et al.*, 2000). The features of a typical base station installation are shown in Figure 2.5. Base stations contain a number of radio transmitters and each of these has the same maximum output power, P_{tx}. The outputs from the individual transmitters are then combined and fed via cables to the base station antenna, which is mounted at the top of a mast (or other suitable structure).

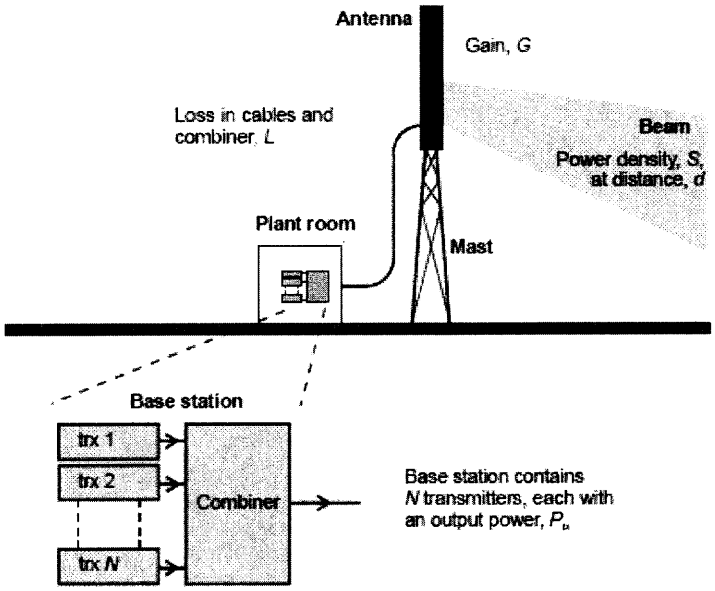


Figure 2.5: A base station contains a number of radio transmitters (trx) whose outputs are combined before being fed to an antenna and transmitted as radio waves. (Mann *et al.*, 2000).

- *Mast:* A mast is a free standing structure (the same as a telegraph pole) which supports antennas at a height where they can transmit and receive radio waves. A mast is typically 15-50 m high and plays no part in the transmission of radio waves. To minimize the environmental impact, more slim line versions with smaller head frames are now in place. These can be painted to blend in with their surroundings, disguised as trees or used in conjunction with street lighting (MOA, 2007).

- *Antennae:* Several types of antennas are used for the transmissions; panel-shaped sector antennas or pole-shaped omni antennas are used to communicate with mobile phones (HPA, 2006). In the most usual construction of a base station there are three sector antennas. In such a case the beam from each antenna has a horizontal spread of 120°, such that the three antennas cover an entire circle (Health Council of the Netherlands, 2000). Dish antennas form terminals for point to point microwave links that communicate with other base stations and link the network together. Sometimes the base stations are connected together with buried cables instead of microwave links (HPA, 2006). In the Kingdom of Bahrain, most Batelco's base stations communicate via cables whereas MTC-Vodafone's base stations communicate via dish antennae. Dish antennas produce narrow conical beams that are 1-2° wide. Typical powers are no more than a few tens of mW because the power is channelled so selectively

towards the receiver. The powers used by dish antennas are very much lower than those used by base station antennas so the exposures produced by signals from dish antennas will be negligible in comparison (Mann *et al.*, 2000).

- *Cables:* which provide the energy and transfer the signal between the transmitter and the antenna.



Figure 2.6: Sector and dish antennae (HPA-2, 2006).

2.5 The Properties of the RF Beam from the Base Station:

Mobile phones communicate by radio signals passing to and from an antenna mounted on the phone and antennas connected to the base station. The radio link from the phone to the base station is known as the uplink and carries the speech from the mobile phone user. A separate radio link from the base station to the phone is known as the down link and this carries the speech from the person to whom the phone user is listening. This principle is illustrated in Figure 2.7 (Mann *et al.*, 2000).

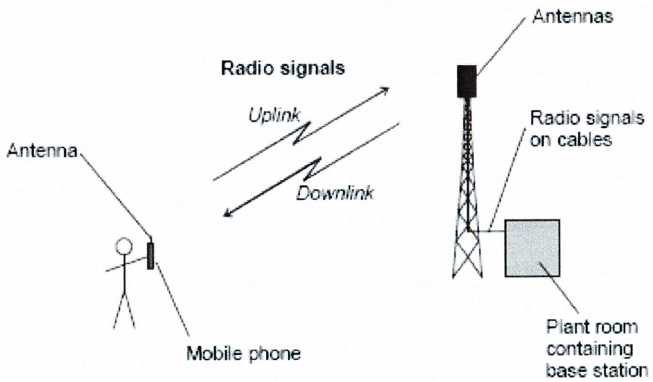


Figure 2.7: Radio signals used for communication between mobile phones and base stations (Mann *et al.*, 2000).

The power from antennas used with macro-cellular base stations is radiated in conical fan-shaped beams, which are essentially directed towards the horizon with a slight downward tilt (illustrated in the Figure 2.8). It causes the radio wave strengths below the antennas and at the base of masts to be very much lower than directly in front of the antennas at a similar distance (HPA, 2006).

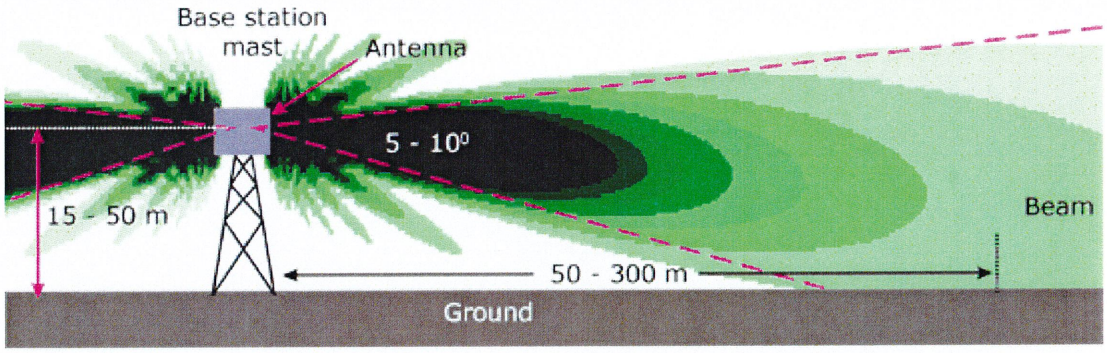


Figure 2.8: The shape of the beam formed by a typical antenna used with a macrocellular base station (HPA, 2006).

The beams formed by antennas used with macro-cellular base stations are narrow in the plane of elevation with typical widths between 5° and 10°. The beams are also tilted slightly downwards so the top edge of the main beam is approximately horizontal whereas the lower edge is directed up to 10° below horizontal. When considering the heights at which antennas tend to be mounted, it implies that the main beam from base station antennas would be expected to reach ground level typically between 50 and 300 m from the foot of a mast (Mann *et al.*, 2000).

At distances closer to the mast than where the main beam reaches ground level, exposure occurs due to weaker beams known as sidelobes, whose power density is not so easy to calculate, unless one has detailed technical information about the beam pattern from the antennas (HPA, 2006).

Certain behavior characteristics of EM fields dominate at one distance from the radiating antenna, while a completely different behavior can dominate at another location. Electrical engineers define boundary regions to categorize behavior characteristics of electromagnetic fields as a function of distance from the radiating source. These regions are: the "Near-Field", "Transition Zone", and "Far-Field". The regional boundaries are usually measured as a function of the wavelength. Figure 2.9 shows these regions and boundaries.

Two things should be stressed: these regions categorize behaviors which vary even within each region; and the boundaries for these regions are approximate "rules of thumb" (more precise boundaries can be defined based primarily on antenna type and antenna size, and even then the experts differ).

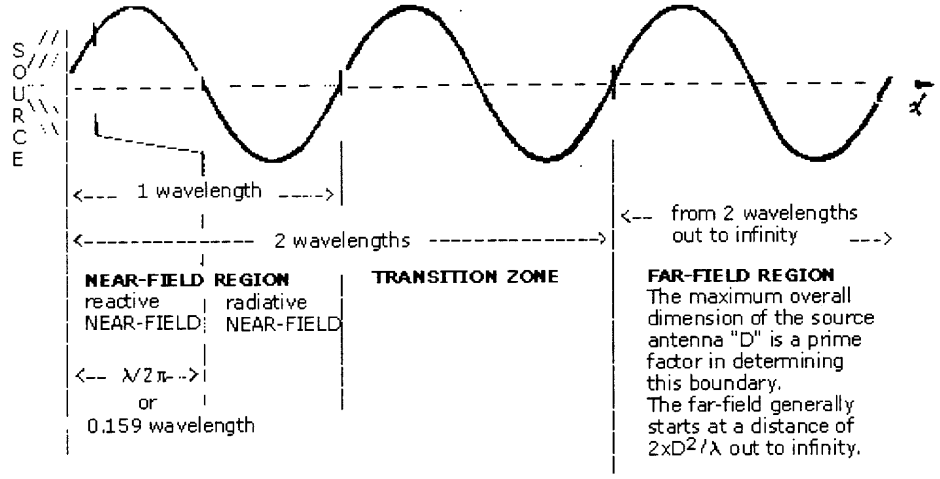


Figure 2.9: Antenna field regions for typical antennas.

The region extending farther than 2 wavelengths away from the source is called the "Far-Field". In the far-field, **E**, **H**, and power density are related by the equations: $\mathbf{E} = \mathbf{H} \times 377$ and $\mathbf{S} = \mathbf{E} \times \mathbf{H}$ which was discussed before.

The region between the near-field and the far-field is called the "Transition Zone". It has a combination of the characteristics found in both the near-field and the far-field. Here it may not always be necessary to measure both **E** and **H** to obtain a good approximation of the EM field, but several measurements are needed to characterize the field.

The region located less than one wavelength from the source is called the "Near-field". Here, the relationship between **E** and **H** becomes very complex, and it requires measurement of both **E** and **H** to determine the power density. Also, unlike the far-field where EM waves are usually characterized by a single polarization type (horizontal, vertical, circular, or elliptical), all four polarization types can be present in the near-field (OSHA, 1990).

Since both the **E** field and the **H** field components of electromagnetic waves are absorbed by living tissue, and since the relationship between **E** and **H** is complicated in the near-field, we must measure both of them when evaluating near-field hazards.

The near-field is further divided into the "reactive" near-field and the "radiative" near-field. The outer boundary of the reactive near-field region is commonly considered to be a distance of $1/2\pi$ times the wavelength ($\lambda/2\pi$ or $0.159\times\lambda$) from the antenna surface. The radiative near-field covers the remainder of the near-field region, from $\lambda/2\pi$ out to λ (one full wavelength).

In the reactive near-field (very close to the antenna), the relationship between the strengths of the **E** and **H** fields is too complex to predict. Either field component (**E** or **H**) may dominate at one point, or the other way dominate at a point only a short distance away. This makes it extremely difficult to find the true power density there. Not only would **E** and **H** both have to be measured, but a new term called the phase relationship between E and H is needed. Present survey meters measure only the magnitude **E** or **H**, not this phase relationship. Although it would be very helpful to know the true power density, our present compliance efforts do not require us to determine it (OSHA, 1990).

As you might have guessed, the reactive near-field region has another surprise in store for you. In this reactive region, not only is the EM wave being radiated outward into space, but there is a "reactive" component to the EM field. Very close to the antenna, energy of an unknown amount is held back and is stored very near the antenna surface. This reactive component can be the source of confusion and danger in attempting measurements in this region. In other regions the power density is inversely proportional to the square of the distance from the antenna. In the vicinity very close to the antenna, the energy level can rise dramatically with only a small additional movement towards the antenna. This energy can be very dangerous (even hazardous) to both humans and measurement equipment where high powers are involved.

When the radiating dimensions of the antenna are much smaller than one wavelength and/or the frequency is low, it is especially important to be aware of the potentially hazardous reactive fields which may exist in the reactive near-field. As you move nearer to the antenna in the reactive near-field, the energy can increase much quicker than what is computed by the

inverse-square law. Some electromagnetic energy is stored in the near-field in the vicinity of the antenna that can be an unsuspected source of dangerous energy. This "reactive field" energy is especially dangerous with high power systems. The closer to the radiating source you get, the more caution should be exercised.

The radiative near-field does not contain any reactive field components from the source antenna. The energy is all radiant energy and as you move further out into the radiative near-field (one half wavelength to 1 wavelength from the source), the **E** to **H** relationship is still complex. Since the radiative near-field is still part of the near-field, caution should still be exercised in relation to personal safety and equipment safety. Metal objects such as steel beams can act as antennas by receiving and then "re-radiating" some of the energy, forming a new radiating surface to consider. Not only does this new radiating surface have its own near-field regions, the energy levels might be shockingly high. Exercise caution near such metal objects.

All near-field readings require special attention. In general, readings taken closer than one wavelength require measurement of both the **E** and **H** fields. While taking measurements in the near-field, you may notice the values for **E** and **H** vary considerably from point to point. A very strong **E** or **H** field strength may exist only inches away from a very weak **E** or **H** field strength. When attempting "power measurement" in the near-field, make an effort to take both the **E** field and the **H** field measurements at the exact same physical location, especially if unusual peaks and valleys are observed from point to point. The variation may be only centimeters apart or may be as much as one meter. How much care to be taken will be obvious to you by observing the meter display for abrupt changes.

Throughout this section the boundaries for the near and far-field regions have been defined only in terms of wavelength. Actually, the boundaries are based on more. The maximum overall dimension (D) of the radiating antenna is a prime factor in determining these boundaries. This dimension is a physically measured length. Above we assumed that "D" was one wavelength or less. For antennas like the ones mounted on houses for TV (dipole antennas), "D" would be the length of the radiating arm; and for a radar set or heat sealer, "D" might be the maximum dimension of the port opening (or aperture) through which the EM wave passes.

In most situations "D" is between one-fourth to one whole wavelength (λ) long, but there are some situations where "D" might be much larger or much smaller than "λ". When "D" is much larger 2 than "λ ", the far-field boundary is not 2 λ as shown in Figure 2.9, but is $2D^2/\lambda$. Therefore, if the maximum overall dimension exceeds "λ", the far-field boundary extends farther out than 2λ. Thus we might be required to measure both the **E** and **H** field components, even beyond the 2λ distance or when the frequency is above the 300 MHz "rule of thumb". But don't panic, these situations are usually the exception, but you should be aware of their existence (OSHA, 1990).

For the antennas most typically used at base stations, the near-field remains limited to a distance of several metres from the antennas. Within the near-field, the field strength outside of the beam strongly decreases as the distance to the beam increases. Simple calculations done by Health Council of the Netherlands reveal that for an antenna with a radiated power of about 20 W, a representative value for the antennas used in the Netherlands, the exposure limit for the general public can only be exceeded within the beam and at a distance of no more than 3 m from the antenna (Health Council of the Netherlands, 2000). Figure 2.10 provides a schematic representation of the calculated field strengths mentioned.

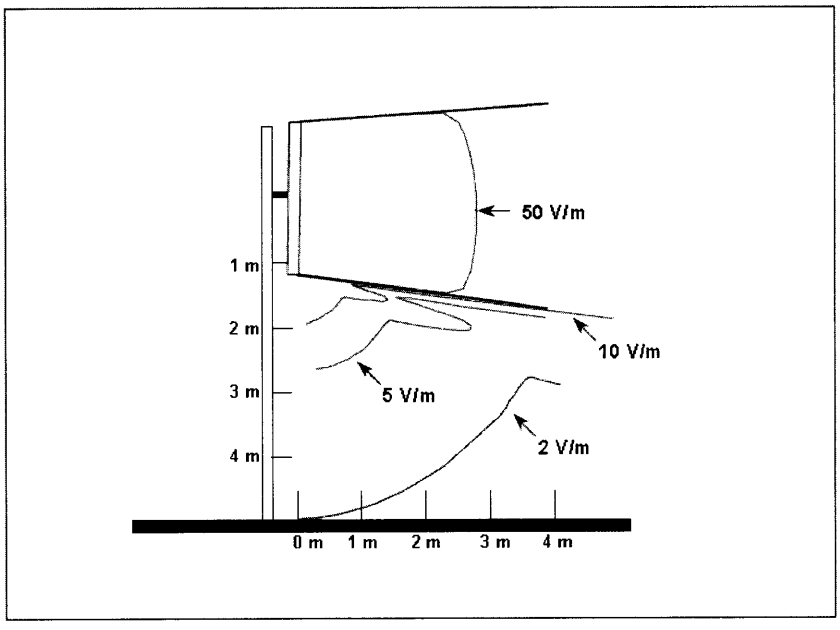


Figure 2.10: Schematic representation of the field strengths near a GSM 900 antenna with a radiated power of about 20 W. (Health Council of the Netherlands, 2000).

CHAPTER 3

3. Guidelines for Limiting Exposure to Radiofrequency Radiation

The two most commonly cited guidelines for standards on limiting exposure to RF fields are International Commission of Non-Ionizing Radiation Protection (ICNIRP) guidelines and the Institute of Electrical and Electronics Engineers (IEEE). Other regulatory bodies that issue guidelines worldwide include the National Radiological Protection Board (NRPB) in the UK, the Federal Communications Commission (FCC) in the USA, the Australian Radiation Protection and Nuclear Safety Agency (ARPANSA) and Health Canada (HC).

In the following, the guidelines for these organizations will be demonstrated and then will be compared and discussed. In most of these guidelines, the limiting values are given as basic restrictions and reference levels for both occupational and general public exposure.

3.1 Guidelines of International Commission of Non-Ionizing Radiation Protection (ICNIRP):

The International Commission of Non-Ionizing Radiation Protection (ICNIRP) is an independent scientific organization responsible for providing guidance and advice on the health hazards of non-ionising radiation exposure. ICNIRP develops international guidelines on limits of exposure to non-ionising radiation .The most recent guidelines on limiting exposure to electromagnetic fields were published in April 1998 (ICNIRP, 1998).

Limiting values are given as basic restrictions and reference levels. Basic restrictions directly relate to established health effects. Appropriate safety factors are included. Reference levels are derived from the basic restrictions for worst-case exposure situations and are in quantities that can be easily measured. They provide levels that can be used to determine compliance with the basic restrictions (ICNIRP, 1999).

Restrictions on the effects of exposure are based on established health effects and are termed basic restrictions. Depending on frequency, the physical quantities used to specify the basic restrictions on exposure to EMF are current density, SAR, and power density. Protection against adverse health effects requires that these basic restrictions are not exceeded (ICNIRP, 1998).

Different scientific bases were used in the development of basic exposure restrictions for various frequency ranges. Between 100 kHz and 10 GHz, basic restrictions on SAR are provided to prevent whole-body heat stress and excessive localized tissue heating; in the 100 kHz–10 MHz range, restrictions are provided on both current density and SAR (ICNIRP, 1998).

Established biological and health effects in the frequency range from 10 MHz to a few GHz are consistent with responses to a body temperature rise of more than 1°C. This level of temperature increase results from exposure of individuals under moderate environmental conditions to a whole-body SAR of approximately 4 W/kg for about 30 min. A whole-body average SAR of 0.4 W/kg has therefore been chosen as the restriction that provides adequate protection for occupational exposure. *An additional safety factor of 5 is introduced for exposure of the public, giving an average whole-body SAR limit of 0.08 W/kg.* The lower basic restrictions for exposure of the general public take into account the fact that their age and health status may differ from those of workers (ICNIRP, 1998).

The basic restrictions for current densities, whole body average SAR, and localized SAR for frequencies between 1 Hz and 10 GHz are presented in Table 3.1.
Reference levels of exposure are provided for comparison with measured values of physical quantities; compliance with all reference levels given in these guidelines will ensure compliance with basic restrictions. If measured values are higher than reference levels, it does not necessarily follow that the basic restrictions have been exceeded, but a more detailed analysis is necessary to assess compliance with the basic restrictions (ICNIRP, 1998).

Where appropriate, the reference levels are obtained from the basic restrictions by mathematical modeling and by extrapolation from the results of laboratory investigations at

specific frequencies. They are given for the condition of maximum coupling of the field to the exposed individual, thereby, providing maximum protection.

Table 3.1: Basic restrictions adopted by ICNIRP for time varying electric and magnetic fields for frequencies up to 10 GHz. (ICNIRP, 1998).

Exposure characteristics	Frequency range	Current density for head and trunk (mA m^{-2}) (rms)	Whole-body average SAR (W kg^{-1})	Localized SAR (head and trunk) (W kg^{-1})	Localized SAR (limbs) (W kg^{-1})
Occupational exposure	up to 1 Hz	40	—	—	—
	1–4 Hz	40/*f*	—	—	—
	4 Hz–1 kHz	10	—	—	—
	1–100 kHz	*f*/100	—	—	—
	100 kHz–10 MHz	*f*/100	0.4	10	20
	10 MHz–10 GHz	—	0.4	10	20
General public exposure	up to 1 Hz	8	—	—	—
	1–4 Hz	8/*f*	—	—	—
	4 Hz–1 kHz	2	—	—	—
	1–100 kHz	*f*/500	—	—	—
	100 kHz–10 MHz	*f*/500	0.08	2	4
	10 MHz–10 GHz	—	0.08	2	4

[a] Note:

1. *f* is the frequency in hertz.
2. Because of electrical inhomogeneity of the body, current densities should be averaged over a cross-section of 1 cm^2 perpendicular to the current direction.
3. For frequencies up to 100 kHz, peak current density values can be obtained by multiplying the rms value by $\sqrt{2}$ (~1.414). For pulses of duration t_p the equivalent frequency to apply in the basic restrictions should be calculated as $f = 1/(2t_p)$.
4. For frequencies up to 100 kHz and for pulsed magnetic fields, the maximum current density associated with the pulses can be calculated from the rise/fall times and the maximum rate of change of magnetic flux density. The induced current density can then be compared with the appropriate basic restriction.
5. All SAR values are to be averaged over any 6-min period.
6. Localized SAR averaging mass is any 10 g of contiguous tissue; the maximum SAR so obtained should be the value used for the estimation of exposure.
7. For pulses of duration t_p the equivalent frequency to apply in the basic restrictions should be calculated as $f = 1/(2t_p)$. Additionally, for pulsed exposures in the frequency range 0.3 to 10 GHz and for localized exposure of the head, in order to limit or avoid auditory effects caused by thermoelastic expansion, an additional basic restriction is recommended. This is that the SA should not exceed 10 mJ kg^{-1} for workers and 2mJ kg^{-1} for the general public, averaged over 10 g tissue.

Table 3.2 summarizes the reference levels for exposure of the general public. The reference levels are intended to be spatially averaged values over the entire body of the exposed individual, but with the important proviso that the basic restrictions on localized exposure are not exceeded (ICNIRP, 1998).

Table 3.2: Reference levels adopted by ICNIRP for general public exposure to time-varying electric and magnetic fields (unperturbed rms values) (ICNIRP, 1998).

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

[a] Note:

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

3.2 National Radiological Protection Board (NRPB) guidelines:

In the UK, national guidelines on exposure to RF radiation were drawn up by National Radiological Protection Board (NRPB) (NRPB, 1993), and have been accepted and implemented by Government Departments and Agencies.

Having reviewed all relevant epidemiological studies, NRPB concluded that the results were inconclusive and did not provide an adequate starting point from which to derive exposure guidelines (NRPB, 1993). Instead, therefore, the guidelines were based on the potential of RF radiation to cause illness or injury through heating of body tissues. While some research had suggested that adverse health effects might occur from exposures lower than those needed to produce significant heating, the evidence for this was not considered sufficiently robust to form a basis for the derivation of exposure guidelines (IEGMP, 2000).

The NRPB exposure guidelines incorporate basic restrictions on the specific energy absorption rate (SAR). For mobile phones, the relevant restrictions are for frequencies between 10 MHz and 10 GHz, and these are given in Table 3.3. To verify that the exposure of an individual is within NRPB guidelines, it is necessary to demonstrate that none of the four

basic restrictions is exceeded. The SAR is averaged over an exposure time and a specified mass of tissue, depending on the tissue region. Averaging times are specified because of the time taken for the temperature of tissues to equilibrate when they are exposed to the radiation (IEGMP, 2000).

Table 3.3: NRPB basic restrictions on exposure in the frequency range 10 MHz to 10 GHz (NRPB, 1993 and IEGMP, 2000).

		Averaging parameters	
Tissue region	SAR limit (W/kg)	Mass (g)	Time (minutes)
Whole body	0.4	–	15
Head, fetus	10	10	6
Neck, trunk	10	100	6
Limbs	20	100	6

These restrictions apply equally to workers and to members of the general public. NRPB has taken the view that they provide adequate protection against harmful thermal effects for all exposed individuals under all conditions.

Since SARs cannot easily be measured in living people, the NRPB guidelines also specify investigation levels for external electromagnetic field strengths, at or below which the basic restriction on whole-body SAR will not be exceeded. If an investigation level is exceeded, more detailed investigation of the resultant SAR is indicated. Table 3.4 shows these investigation levels for the frequency range covered by mobile phones.

Table 3.4: NRPB investigation levels for exposure at mobile telecommunications frequencies (NRPB, 1993 and IEGMP, 2000).

Frequency (MHz)	Electric field strength (V/m)	Magnetic field strength (A/m)	Power density (W/m^2)
400 – 800	100	0.26	26
800 – 1550	$125f$	$0.33f$	$41f^2$
1550 – 3000	194	0.52	100

f is the frequency in GHz.

3.3 The Institute of Electrical and Electronics Engineers (IEEE) standards:

IEEE's recommendations on radiofrequencies were published in 1992 (IEEE, 1992), and later approved by the American National Standards Institute (Levallois *et al.*, 1997). The basic restrictions applicable to mobile technology as proposed by the IEEE (IEEE, 1992) are shown in table 3.5:

Table 3.5: Basic restrictions for general public exposure according to IEEE.

	Averaging parameters		
Tissue region	**SAR (W/kg)**	**Mass (g)**	**Time (minutes)**
Whole body	0.08	--	30
Any tissue	1.6	1	30
Limbs, wrists and ankles	4	10	30

The recommendations for exposure in general public (uncontrolled environments) presented in Table 3.6. The exposure limits presented involve average field strengths or power densities for 30 minutes from 3 MHz to 3 GHz. These limits provide adequate protection if:

- The average per-second induced current in a standing individual does not exceed 45 mA in each foot in the frequency band between 100 kHz and 100 MHz;
- It is an average whole-body exposure;
- The additive effect of different frequencies must be considered;
- These frequencies must be modified for pulsed exposure, taking into account the exposure time and the pulse widths.

Table 3.6: Exposure limits recommended by IEEE for radiofrequencies for general public (uncontrolled environment) (IEEE, 1992 and Levallois *et al.*, 1997).

	UNDISTURBED FIELDS (rms)		**POWER DENSITY (W/m^2)**
FREQUENCY	**ELECTRIC (V/m)**	**MAGNETIC (A/m)**	
100–1340 kHz	614	16.3/*f*	—
1.34–3 MHz	823.8/*f*	16.3/*f*	—
3–30 MHz	823.8/*f*	16.3/*f*	—
30–100 MHz	27.5	158.3/*f* 1.668	—
100–300 MHz	27.5	0.0729	2
300–3000 MHz			*f*/150
3–15 GHz			*f*/150
15–300 GHz			100

f : frequency (MHz)

The recommended exposure limits for field strength and power density may be exceeded if the SAR does not exceed the values in table 3.5 (Levallois *et al.*, 1997).

3.4 The Federal Communications Commission (FCC) Guidelines:

In 1996, the FCC adopted updated guidelines for evaluating human exposure to RF fields from fixed transmitting antenna, such as those used for cellular and mobile phones base stations. The FCC's guidelines are identical to those recommended by the National Council on Radiation Protection and Measurements (NCRP) , which is a non-profit corporation chartered by Congress to develop information and recommendations concerning radiation protection.

The FCC's guidelines also resemble the 1992 guidelines recommended by the Institute of Electrical and Electronics Engineers (IEEE), which is a non-profit technical and professional engineering society, and endorsed by the American National Standards Institute (ANSI), which is also a non-profit, privately-funded, membership organization that coordinates development of voluntary national standards in the United States (FCC, 2006).

The FCC adopted limits for Maximum Permissible Exposure (MPE) are generally based on recommended exposure guidelines published by the National Council on Radiation Protection and Measurements (NCRP) in "Biological Effects and Exposure Criteria for Radiofrequency Electromagnetic Fields". In the frequency range from 100 MHz to 1500 MHz, exposure limits for field strength and power density are also generally based on the MPE limits found in Section 4.1 of "IEEE Standard for Safety Levels with Respect to Human Exposure to Radio Frequency Electromagnetic Fields, 3 kHz to 300 GHz,", and approved for use as an American National Standard by the American National Standards Institute (ANSI) (Cleveland *et al.*, 1997).

The FCC's limits of specific absorption rate (SAR) for occupational and general population are given in Table 3.7, whereas Table 3.8 shows the MPE limits for field strength and power density for general population.

Table 3.7: FCC limits for whole-body and localized (partial-body) exposure (Cleveland and Ulcek, 1999).

Specific Absorption Rate (SAR)	
Occupational/Controlled Exposure (100 kHz - 6 GHz)	**General Uncontrolled/Exposure (100 kHz - 6 GHz)**
< 0.4 W/kg whole-body **≤ 8 W/kg partial-body**	**< 0.08 W/kg whole-body** **≤ 1.6 W/kg partial-body**

Table 3.8: Limits for Maximum Permissible Exposure (MPE) for general population (uncontrolled exposure) (FCC and LSGAC, 2000; Cleveland *et al.*, 1997).

Frequency Range (MHz)	Electric Field Strength (E) (V/m)	Magnetic Field Strength (H) (A/m)	Power Density (S) (mW/cm^2)	Averaging Time $\|E\|^2$, $\|H\|^2$ or S (minutes)
0.3-1.34	614	1.63	(100)*	30
1.34-30	824/f	2.19/f	$(180/f^2)$*	30
30-300	27.5	0.073	0.2	30
300-1500	--	--	f/1500	30
1500-100,000	--	--	1.0	30

f = frequency in MHz *Plane-wave equivalent power density

Note: General population/uncontrolled exposures apply in situations in which the general public may be exposed, or in which persons that are exposed as a consequence of their employment may not be fully aware of the potential for exposure or can not exercise control over their exposure.

3.5 The Australian Radiation Protection and Nuclear Safety Agency (ARPANSA) Guidelines:

Mandatory limits on exposure to RF fields are based on established health effects and are termed 'basic restrictions'. Protection against established adverse health effects requires that these basic restrictions are not exceeded. Depending on frequency, the physical quantities used to specify the basic restrictions are current density (J), specific absorption rate (SAR), specific absorption (SA) and power flux density (S) (ARPANSA, 2002).

However, these mandatory basic restrictions are specified as quantities that are often impractical to measure. Therefore, reference levels (unperturbed ambient electric and magnetic fields, induced limb currents and contact currents), utilising quantities that are more practical to measure, are provided as an alternative means of showing compliance with the mandatory basic restrictions. Provided that all basic restrictions are met and adverse effects can be excluded, the reference levels may be exceeded. The reference levels have been conservatively formulated such that compliance with the reference levels given in these guidelines will ensure compliance with the basic restrictions.

The basic restrictions for whole-body average SAR and spatial peak SAR are specified. Different criteria were used in the development of basic restrictions for various frequency ranges (ARPANSA, 2002)., i.e.

(a) In the frequency range between 100 kHz and 6 GHz, basic restrictions on whole body average SAR are provided to prevent whole-body heat stress. Basic restrictions on spatial peak SAR, in the head and torso and in the limbs, are intended to prevent excessive localised temperature rise in tissue. Due to thermal inertia of tissue, a six minute averaging time is appropriate for time averaged SAR measurements (see Table 3.9).

(b) In the frequency range between 100 kHz and 6 GHz range, restrictions are provided on both current density and SAR where both quantities are relevant to this frequency range (see Table 3.9).

Table 3.9: Basic restrictions for whole-body average SAR and spatial peak SAR (ARPANSA, 2002).

Exposure category	Frequency range	Whole-body average SAR (W/kg)	Spatial peak SAR in the head & torso (W/kg)	Spatial peak SAR in limbs (W/kg)
Occupational	100 kHz–6 GHz	0.4	10	20
General public	100 kHz–6 GHz	0.08	2	4

Table 3.10 specifies the reference levels for time averaged exposure to ambient electric (**E**) and magnetic (**H**) fields.

Table 3.10: Reference levels for time averaged exposure to rms electric and magnetic fields (unperturbed field) (ARPANSA, 2002).

Exposure category	Frequency range	E-field strength (V/m rms)	H-field strength (A/m rms)	Equivalent plane wave power flux density S_{eq} (W/m^2)
Occupational	100 kHz – 1 MHz	614	$1.63/f$	–
	1 MHz – 10 MHz	$614/f$	$1.63/f$	$1000/f^2$ (see note 5)
	10 MHz – 400 MHz	61.4	0.163	10 (see note 5)
	400 MHz – 2 GHz	$3.07 \times f^{0.5}$	$0.00814 \times f^{0.5}$	$f/40$
	2 GHz – 300 GHz	137	0.364	50
General public	100 kHz – 150 kHz	86.8	4.86	–
	150 kHz – 1 MHz	86.8	$0.729/f$	–
	1 MHz – 10 MHz	$86.8/f^{0.5}$	$0.729/f$	–
	10 MHz – 400 MHz	27.4	0.0729	2 (see note 6)
	400 MHz – 2 GHz	$1.37 \times f^{0.5}$	$0.00364 \times f^{0.5}$	$f/200$
	2 GHz – 300 GHz	61.4	0.163	10

NOTES:

1 ***f* is the frequency in MHz.**

2 For frequencies between 100 kHz and 10 GHz, S_{eq}, E^2 and H^2 must be averaged over any 6 minute period.

The **E** and **H** reference levels have been derived from the basic restrictions by mathematical modelling and laboratory investigations. They are given for the condition of maximum coupling of the field to the exposed individual for all circumstances and, therefore, are generally more conservative than the corresponding basic restrictions (ARPANSA, 2002).

For the purposes of demonstrating compliance with the basic restrictions, the reference levels for the electric and magnetic fields should be considered separately and not additively. This is because, for protection purposes, the currents induced by electric and magnetic fields are not additive.

3.6 Health Canada:

At frequencies between 100 kHz and 10 GHz, SAR limits take precedence over field strength and power density limits and shall not be exceeded. The SAR should be determined for cases where exposures take place at 20 cm or less from the source. For conditions where SAR determination is impractical, field strength or power density measurements shall be carried

out. In cases where SAR determination is appropriate, the values in Table 3.11 shall not be exceeded (Health Canada, 1999):

Table 3.11: SAR limits for persons not classed as RF and microwave exposed workers (including the general public) (Health Canada, 1999)

Condition	*SAR* Limit (W/kg)
The *SAR* averaged over the whole body mass	0.08
The local *SAR* for head, neck and trunk, averaged over any one gram (g) of tissue*	1.6
The *SAR* in the limbs, as averaged over 10 g of tissue*	4

* Defined as a tissue volume in the shape of a cube.

A person, other than an RF and microwave exposed worker, shall not be exposed to electromagnetic radiation in a frequency band listed in Column 1 of Table 3.12 if the field strength exceeds the value given in Column 2 or 3 of Table 3.12, when averaged spatially and over time, or if the power density exceeds the value given in Column 4 of Table 3.12, when averaged spatially and over time.

The spatial averaging is carried out over an area equivalent to the vertical cross-section of the human body (projected area). A time-averaging period of 0.1 h (6 min) should be employed for frequencies up to 15 000 MHz (Health Canada, 1999).

Table 3.12: Exposure limits for persons not classed as RF and microwave exposed workers (including the general public) (Health Canada, 1999)

1 Frequency (MHz)	2 Electric Field Strength; rms (V/m)	3 Magnetic Field Strength; rms (A/m)	4 Power Density (W/m^2)	5 Averaging Time (min)
0.003–1	280	2.19		6
1–10	$280/f$	$2.19/f$		6
10–30	28	$2.19/f$		6
30–300	28	0.073	2*	6
300–1 500	$1.585f^{0.5}$	$0.0042f^{0.5}$	$f/150$	6
1 500–15 000	61.4	0.163	10	6
15 000–150 000	61.4	0.163	10	$616\,000/f^{1.2}$
150 000–300 000	$0.158f^{0.5}$	$4.21 \times 10^{-4}f^{0.5}$	$6.67 \times 10^{-5}f$	$616\,000/f^{1.2}$

* Power density limit is applicable at frequencies greater than 100 MHz.

3.7 Italian Exposure Limits:

Whereas the previous limits and guidelines were based on scientific evidence the Italian regulations for RF exposure limits based on the precautionary principle, the recourse to which would be justified by possible long-term effect of EMF exposure. Compared to other exposure limits values which are given as basic restrictions and reference levels, the Italian exposure limits is given as three different exposure levels, *exposure limits, attention levels,* and *quality goals,* respectively (Vecchia, 2007).

Vecchia stated that "Exposure limits cannot be exceeded under any circumstance, attention levels cannot be exceeded in residential environments, and quality goals are additional limits set by the State in order to minimize exposure. Both attention values and quality goals are explicitly defined as cautionary limits for long-term effects" (Vecchia, 2007). The table shows the values of the above limits:

Table 3.13: Restriction on RF exposure in Italy (Vecchia, 2007).

Frequency range		**Electric field (V/m)**	**Magnetic field (A/m)**	**Power density (W/m^2)**
100 kHz – 3 MHz	Exposure limit	60	0.2	---
	Attention value	6	0.016	---
	Quality goal	6	0.016	---
3 MHz – 3 GHz	Exposure limit	20	0.05	1
	Attention value	6	0.016	0.1
	Quality goal	6	0.016	0.1
3 GHz – 300 GHz	Exposure limit	40	0.1	4
	Attention value	6	0.016	0.1
	Quality goal	6	0.016	0.1

3.8 Summary and Conclusion about Guidelines:

Table 3.14 summarizes the basic restrictions for general public exposure of the previous organizations using the physical quantity SAR in unit of W/kg:

Table 3.14: Comparison between different basic restrictions for general public exposure.

	Whole body SAR (W/kg)	Localized SAR (head and trunk) (W/kg)	Localized SAR (limbs, wrists and ankles) (W/kg)
ICNIRP	0.08	2	4
NRPB	0.4	10	20
IEEE	0.08	1.6	4
FCC	0.08	1.6	----
ARPANS	0.08	2	4
CANADA	0.08	1.6	4

Note that Basic restrictions are directly related to established health effects.

NRPB has one basic restriction for both occupational and general public. As a result, its values are the highest. All other organizations have the same value of SAR for whole body (which is 0.08 W/kg) and for localized SAR (limbs) (which is 4 W/kg).

Tables 3.15, 3.16 and 3.17 summarize the Reference Levels for general public exposure for previous organizations for GSM 900 (925 – 960 MHz), GSM 1800 (1805 – 1880 MHz) and UMTS (2110 – 2170 MHz):

Table 3.15: Comparison between different reference levels for general public exposure for frequency band of GSM 900 (925 – 960 MHz).

	E-field strength (V/m)	H-field strength (A/m)	Power density (W/m^2)
ICNIRP	41.82 – 42.60	0.113 – 0.115	4.63 – 4.80
NRPB	115.63 – 120.00	0.305 – 0.317	35.08 – 37.79
IEEE	----	----	6.17 – 6.40
FCC	----	----	6.17 – 6.40
ARPANS	41.67 – 42.45	0.111 – 0.113	4.63 – 4.80
CANADA	48.21 – 49.11	0.128 – 0.130	6.17 – 6.40
ITALY	6	0.016	0.1

Table 3.16: Comparison between different reference levels for general public exposure for frequency band of GSM 1800 (1805 – 1880 MHz).

	E-field strength (V/m)	H-field strength (A/m)	Power density (W/m^2)
ICNIRP	58.42 – 59.62	0.157 – 0.160	9.03 – 9.40
NRPB	194	0.52	100
IEEE	----	----	12.03 – 12.53
FCC	----	----	10
ARPANS	58.20 – 59.40	0.155 – 0.158	9.03 – 9.40
CANADA	61.4	0.163	10
ITALY	6	0.016	0.1

Table 3.17: Comparison between different reference levels for general public exposure for frequency band of UMTS (2110 – 2170 MHz).

	E-field strength (V/m)	H-field strength (A/m)	Power density (W/m^2)
ICNIRP	61	0.16	10
NRPB	194	0.52	100
IEEE	----	----	14.07 – 14.47
FCC	----	----	10
ARPANS	61.4	0.163	10
CANADA	61.4	0.163	10
ITALY	6	0.016	0.1

We can notice that Italian limit is the lowest limit among the other. Also the Italian limit, unlike others limits, is frequency independent. The lowest reference levels values from other limits are those adopted by ICNIRP and ARPANS. However, the other limits are not so far from these limits. The highest reference levels values are those adopted by NRPB.

In the Kingdom of Bahrain, the exposure limit of power density equal to 0.1 W/m^2 was recommended by the Pollution Control Section, Public Commission for the Protection of Marine Resources, Environment and Wildlife (PCPMREW) but not yet adopted by the Government (according to Mr. Mirza Salman Khalaf, *the Head of Pollution Control Section*).

In this study, both the ICNIRP limit and the limit recommended by PCPMREW (0.1 W/m^2) will be used in the discussion and assessment of the results.

CHAPTER 4

4. Methodology

This chapter describes the equipments used in measuring RF radiation from the mobile phone base stations, the criteria followed in choosing these base stations and the procedure of recording the measurement.

4.1 Equipments and Software

All RF radiation measurements from mobile phone base stations were recorded using a portable spectrum analyser connected to antenna. The spectrum analyser model is SPECTRAN® HF-6080 which is the best model among various models of HF detectors made by Aaronia AG, Germany. Some of the most important specifications of the devices are:

- Frequency range: 1 MHz to 7 GHz
- Level range: -90 dBm to 30 dBm
- Power flux density range: 10 fW/m^2 to 100 W/m^2 (where fW=10^{-15} W)
- Filter bandwidth range: 10 KHz to 50 MHz
- Precision base unit +/- 3 dBm

The antenna connected to the spectrum analyser, HyperLOG® 6080, is a logarithmic-periodic antenna and it is a single broadband antenna for the complete frequency range from 680MHz to 18GHz. The antenna is calibrated precisely in the Aaronia laboratories before dispatch. It's gain is 5dBi and it has integrated 5/8" tripod socket and its dimensions is (340×200×25) mm.

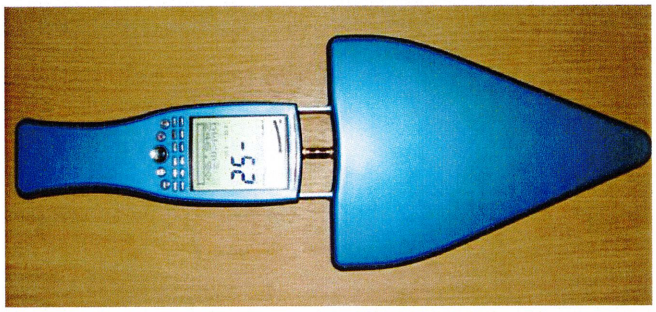


Figure 4.1: The spectrum analyser connected with the antenna via SMA adapter.

Other equipments that used are tripod, adopter and five meters extension cable for long term (24 hours) measurements.

Three software were used in this study. First, the software used in processing and analysing data is The Microsoft® Office Excel 2003 Program. The second software is "Google Earth" which was used to specify the locations of the base stations and to determine the distance between each base station and the point of measurement. The third software used is SPECTRAN spectrum analyser software "LCS" which was used in downloading the data saved in the spectrum analyser during the long term measurements.

4.2 The Method Used in Choosing the Sample of Base Stations

There are two network operator of mobile phone in the Kingdom of Bahrain, Bahrain Telecommunications Company (Batelco) and Mobile Telecommunications Company (MTC-Vodafone). The two operators have about 310 mobile phone base stations spread throughout the Kingdom at the time of writing this thesis. Batelco have about 195 base stations, whereas MTC have about 115 base stations. From the 310 base stations, there are about 26 base stations which are in restricted area or in non occupied area in the Southern governorate. So the reminding accessible base stations are 284 base stations. The distribution of these allowed base stations illustrated in Table 4.1. Note that the number in bracket is the number of accessible base stations.

Table 4.1: Distribution of base stations at the five governorates in the Kingdom of Bahrain.

Governorate	BATELCO	MTC-Vodafone
	Total	Total
1. Capital	62	33
2. Muharraq	23	14
3. Northern	40	24
4. Central	39	24
5. Southern	31 (13)	20 (12)
TOTAL	195 (177)	115 (107)
	310 (284 accessible)	

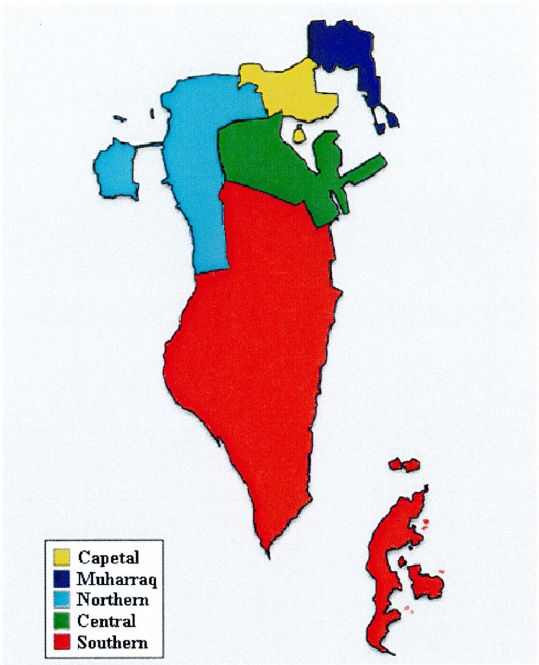


Figure 4.2: The five governorates in the Kingdom of Bahrain.

To estimate the minimum sample size (n) required (according Scheaffer *et al.*, 1990), the following formula was used:

$$n = \left[\frac{(Z_{\alpha/2} \times \sigma}{E} \right]^2 \qquad (6)$$

Where n is the required sample, σ is the standard deviation, $Z_{\alpha/2}$ is the normal curve area which is equal to 1.96 and E is the sampling error size. The σ for 8 readings of base stations was calculated and equal to 0.8. For 20% of sampling error, the minimum sample size will be:

$$n = \left[\frac{(1.96 \times 0.8}{0.2} \right]^2 = 61 \qquad (7)$$

The sample size that was chosen according to the previous result is 70 base stations. This number of base station represented approximately 25% of the total allowed base stations (285 base stations). This ratio was applied for the number of base stations of each operator in each governorate separately. The final number of base stations for both operators in each governorate in the following table:

Table 4.2: The numbers of base stations that were chosen for the measurements in the five governorates in the Kingdom of Bahrain.

Governorate	BATELCO	MTC-Vodafone
	25%	25%
1. Capital	16	8
2. Muharraq	6	3
3. Northern	10	6
4. Central	10	6
5. Southern	3	2
TOTAL	45	25
	70	

The 70 base stations among the total number were chosen according to following criteria:

- The base station should be in the middle or next to residential area. The base stations in open and non-residential area were excluded.
- The antenna of base station must be seen from the point of measurement and not shielded by buildings or trees.

For long term (24 hours) measurements, the sites selected according to possibility of access to the roof of a house located within distance of not more than 300 m from the mobile phone base station. The availability of electricity also required.

Additional measurements were made in the vicinity of the base station to determine the RF radiation distribution in the streets and roads around the base station. One base station was chosen to do this type of measurements.

4.3 Surveying Procedure

After the base stations were specified according to previous criteria, we started doing survey. To ensure that we record the maximum level of each base station, we follow the next procedure:

1. We actually went to area and located the base station and took overall look around it.
2. A random point of measurement was specified between 50 and 350 m far away from the base station. This range of distance was chosen according to the theoretical aspect which states that the main beam of the RF radiation from the base station reaches the

ground at that range of distance, dependent on the height of base station (see section 2.5 and Figure 2.8). Moreover, we do some investigations for two base stations and found that the maximum power density is about 100 m from the base station. (see appendix 4).

3. For each base station we took measurements in several points at different distances (between 50 and 350 m) and various directions (east, west, north and south).
4. Using the above results, we decided which one of these points were the maximum point of measurement and started to record all measurements at this point.

The method of recording measurements by using the spectrum anlayser is:

1. The spectrum analyser was connected to the antenna.
2. The spectrum analyser was turned on.
3. The key 7 was pressed for sitting up optimal parameters for measurement of GSM 900.
4. The data was recorded and the procedure was repeated for other two band of mobile phone base station, GSM1800 and UMTS.

The procedures for long term (24 hours) measurements are as following:

1. The antenna was fixed above the tripod on roof of building.
2. The antenna was connected to the spectrum analyser via 5 m cable.
3. The spectrum analyser was put indoor to avoid direct sunlight, dust and rain.
4. The number of readings was set 240 and the time between readings is 360 seconds.
5. After 24 hours all equipments were disconnected and the data were downloaded using spectrum analyser software "LCS".

The procedure for street mapping of power density include printing the map of area around the base station, locate the points of measurements and follow the previous steps for normal measurements for GSM900 only.

CHAPTER 5

5. Results and Discussion

In this chapter, all results of the three types of measurements, environmental measurements, long term measurements of RF radiation and street mapping of power density, stated and discussed.

5.1 Environmental Measurements:

The obtained results for the 70 base stations are summarized in Tables 5.1, 5.2, 5.3, 5.4 and 5.5. The abbreviations used in these tables are:

- #: The identification number of each measurement. The letter indicates the first letter of the governorate.
- Town: The town where the measurement carried out.
- Address: The address of the point where measurement done.
- Operator: The mobile phone network operator, either Batelco or MTC.
- Distance: The horizontal distance from the point of measuring to the base station.
- Frequency band: GSM900, GSM1800 or UMTS.
- Freq. (MHz): The frequency in unit of MHz.
- dBm: the power ratio in decibel (dB) of the measured power referenced to reference.
- $\mu W/m^2$: The power density in unit of $\mu W/m^2$.
- V/m: The electric field in unit of V/m.
- mA/m: The magnetic field in unit of mA/m.
- % of ICNIRP limits: The percentage of the measuring relative to ICNIRP limits calculated by the device, spectrum analyser, and it is not same as ICNIRP limits discussed in section 3.1.
- % of PCPMREW limit: The percentage of the measuring relative to the limit proposed by the Pollution Control Section of the Public Commission for the Protection of Marine Resources, Environment and Wildlife (PCPMREW) in Bahrain.



Figure 5.1: The map for the locations of the 9 base stations that was measured at Al Muharraq Governorate.

Table 5.1: The results of measuring RF radiation from 9 base stations in Al Muharraq Governorate.

#	Town or Area	Address	Operator	Distance	Frequency Band	Freq. (MHz)	dBm	Power Density ($\mu W/m^2$)	E-Field (V/m)	H-Field (mA/m)	% of ICNIRP Limits*	% of PCPMREW Limit
M1	Al Hidd-1	Hatim Altaie Avenue Block: 110	MTC	169 m	GSM 900 GSM 1800 UMTS	957 1869 2112	-14 -46 -32	1800 3.60 116.28	0.825 0.037 0.209	2.190 0.098 0.556	1.93 0.06 0.34	1.8 0.0036 0.1163
M2	Al Hidd-2	Hatim Altaie Avenue Block: 109	Batelco	154 m	GSM 900 GSM 1800 UMTS	946 1861 2112	-24 -27 -63	155.66 313.37 0.109	0.242 0.344 0.006	0.643 0.912 0.017	0.57 0.57 0.01	0.1557 0.3134 0.0001
M3	Arad	Avenue: 46 Block: 224	Batelco	203 m	GSM 900 GSM 1800 UMTS	948 1856	-19 -32 Not	524.60 89.55 Recorded	0.445 0.184	1.180 0.488	1.05 0.31	0.5246 0.0896
M4	Qalali-1	Road: 5219 Block: 252	MTC	197 m	GSM 900 GSM 1800 UMTS	927 1811 2114	-34 -43 -43	15.73 7.3 9.61	0.077 0.055 0.06	0.204 0.145 0.160	0.17 0.09 0.10	0.0157 0.0073 0.0096
M5	Qalali-2	Avenue: 58 Block: 251	Batelco	168 m	GSM 900 GSM 1800 UMTS	949 1816	-20 -48 Not	410.33 2.33 Recorded	0.393 0.030	1.044 0.079	0.92 0.05	0.4103 0.0023
M6	Busaiteen	House: 2818 Road: 2653 Block: 226	Batelco	170 m	GSM 900 GSM 1800 UMTS	946 1869 2147	-15 -54 -61	1250 0.5884 0.1712	0.688 0.015 0.008	1.826 0.040 0.021	1.62 0.02 0.01	1.25 0.0006 0.0002
M7	Souq Al Muharraq	House: 1215 Road: 833 Block: 208	Batelco	105 m	GSM 900 GSM 1800 UMTS	954 1806 2112	-20 -36 -38	387.56 33.37 32.44	0.382 0.112 0.111	1.014 0.298 0.293	0.89 0.19 0.18	0.3876 0.0334 0.0324
M8	Al Hala-1	House: 650 Sh. Isa Avenue Block: 210	MTC	110 m	GSM 900 GSM 1800 UMTS	955 1811 2114	-16 -39 -37	921.62 20.00 41.28	0.589 0.087 0.125	1.564 0.230 0.331	1.38 0.14 0.20	0.9216 0.0200 0.0413
M9	Al Hala-2	House: 40 Road: 1601 Block: 216	Batelco	177 m	GSM 900 GSM 1800 UMTS	946 1861 2128	-17 -29 -55	922 185.39 0.6438	0.552 0.264 0.016	1.466 0.703 0.041	1.30 0.44 0.02	0.8092 0.1854 0.0006

* Note that % of ICNIRP limit in this table is calculated by the spectrum analyser and it is not same as limit issued by ICNIRP (see section 3.1)



Figure 5.2: The map for the locations of the 16 base stations that was measured at the Capital Governorate.

Table 5.2: The results of measuring RF radiation from 24 base stations in the Capital Governorate.

#	Town	Address	Operator	Distance	Frequency Band	Freq. (MHz)	dBm	Power Density ($\mu W/m^2$)	E-Field (V/m)	H-Field (mA/m)	% of ICNIRP Limits	% of PCPMREW Limit
CM 1	Sanabis	Road: 812 Block: 408	MTC	122 m	GSM 900	956	-11	3400	1.133	3.007	2.66	3.4000
					GSM 1800	1806	-20	1440	0.737	1.958	1.26	1.4400
					UMTS	2114	-39	25.67	0.098	0.261	0.16	0.0257
CM 2	Suqayya -1	Suqayya Avenue Block: 328	MTC	96 m	GSM 900	957	-15	1290	0.699	1.855	1.64	1.2900
					GSM 1800	1815	-34	55.84	0.145	0.385	0.24	0.0558
					UMTS	2112	-37	41.71	0.125	0.333	0.20	0.0417
CM 3	Zing	Al Qadisiya Avenue Block: 330	Batelco	202 m	GSM 900	950	-12	2790	1.026	2.724	2.42	2.7900
					GSM 1800	1806	-45	4.20	0.040	0.106	0.06	0.0042
					UMTS	2127	-40	21.76	0.091	0.240	0.14	0.0218
CM 4	Um Al Hasam	---	Batelco	170 m	GSM 900	949	-16	1020	0.623	1.653	1.47	1.0200
					GSM 1800	1877	-50	1.49	0.024	0.063	0.03	0.0015
					UMTS	2127	-40	18.81	0.084	0.224	0.13	0.0188
CM 5	Mahooz	---	Batelco	190 m	GSM 900	950	-26	104.40	0.198	0.526	0.46	0.1044
					GSM 1800	1867	-47	3.06	0.034	0.090	0.05	0.0031
					UMTS	2127	-54	0.749	0.017	0.045	0.02	0.0007
CM 6	Jufair-1	---	MTC	225 m	GSM 900	957	-18	713.95	0.519	1.377	1.21	0.7139
					GSM 1800	1811	-33	75.17	0.168	0.447	0.28	0.0752
					UMTS	2114	-35	65.46	0.157	0.417	0.25	0.0655
CM 7	Jufair-2	---	Batelco	195 m	GSM 900	950	-25	125.22	0.217	0.577	0.51	0.1252
					GSM 1800	1813	-45	4.72	0.042	0.110	0.007	0.0047
					UMTS	2112	-65	0.0687	0.005	0.014	0.00	0.0001
CM 8	Jufair-3	---	MTC	99 m	GSM 900	954	-19	453.11	0.413	1.097	0.97	0.4531
					GSM 1800	1813	-34	63.88	0.155	0.412	0.26	0.0639
					UMTS	2112	-37	41.79	0.126	0.334	0.20	0.0418
CM 9	Exhibition	---	MTC	123 m	GSM 900	955	-14	1710	0.804	2.134	1.89	1.7100
					GSM 1800	1806	-22	868.46	0.572	1.518	0.97	0.8685
					UMTS	2114	-37	37.63	0.119	0.316	0.19	0.0376

* Note that % of ICNIRP limit in this table is calculated by the spectrum analyser and it is not same as limit issued by ICNIRP (see section 3.1)

Continued Table 5.2: The results of measuring RF radiation from 24 base stations in the Capital Governorate.

#	Town	Address	Operator	Distance	Frequency Band	Freq. (MHz)	dBm	Power Density ($\mu W/m^2$)	E-Field (V/m)	H-Field (mA/m)	% of ICNIRP Limits	% of PCPMREW Limit
CM 10	Al Hoora	House: 937 Road: 1812 Block: 318	Batelco	242 m	GSM 900 GSM 1800 UMTS	945 1859 2128	-21 -29 -37	301.47 190.57 35.86	0.337 0.268 0.116	0.895 0.711 0.309	0.79 0.45 0.19	0.3015 0.1906 0.0359
CM 11	Qudaybia	---	Batelco	173 m	GSM 900 GSM 1800 UMTS	950 1859 2127	-23 -29 -37	182.51 186.48 43.67	0.262 0.265 0.128	0.696 0.704 0.341	0.61 0.44 0.21	0.1825 0.1865 0.0437
CM 12	Adlia	---	Batelco	283 m	GSM 900 GSM 1800 UMTS	945 1870 2128	-19 -39 -38	499.57 18.08 33.88	0.434 0.083 0.113	1.152 0.219 0.300	1.02 0.13 0.18	0.4996 0.0181 0.0339
CM 13	Suqayya -2	House: 117 Road: 2803 Block: 328	MTC	159 m	GSM 900 GSM 1800 UMTS	955 1808 2112	-16 -24 -35	1000 576.30 57.24	0.615 0.466 0.147	1.633 1.237 0.390	1.44 0.79 0.24	1.0000 0.5763 0.0572
CM 14	Bab Al Bahrain	---	Batelco	124 m	GSM 900 GSM 1800 UMTS	946 1861 2128	-24 -34 -45	174.26 66.57 6.84	0.256 0.158 0.05	0.680 0.420 0.135	0.60 0.26 0.08	0.1743 0.0666 0.0068
CM 15	Awadiya	Build.: 1138 Road: 615 Block: 306	Batelco	161 m	GSM 900 GSM 1800 UMTS	947 1880 2142	-17 -48 -59	723.18 2.59 0.2632	0.522 0.31 0.010	1.386 0.083 0.026	1.23 0.05 0.01	0.7232 0.0026 0.0003
CM 16	Salmania-1	Build.: 749 Road: 1124 Block: 311	MTC	170 m	GSM 900 GSM 1800 UMTS	956 1810 2112	-19 -29 -29	513.92 173.50 248.03	0.440 0.256 0.306	1.168 0.679 0.811	1.03 0.43 0.50	0.5139 0.1735 0.2480
CM 17	Al Bilad Al Qadeem	---	Batelco	143 m	GSM 900 GSM 1800 UMTS	947 1811 2150	-18 -45 -54	664.80 4.59 0.7883	0.500 0.042 0.017	1.329 0.111 0.046	1.18 0.07 0.02	0.6648 0.0046 0.0008
CM 18	Noaim	Road: 1413 Block: 314	Batelco	120 m	GSM 900 GSM 1800 UMTS	946 1862 2128	-19 -42 -53	505.44 8.69 0.9339	0.436 0.057 0.019	1.158 0.152 0.050	1.03 0.09 0.03	0.5054 0.0087 0.0009

* Note that % of ICNIRP limit in this table is calculated by the spectrum analyser and it is not same as limit issued by ICNIRP (see section 3.1)

Continued Table 5.2: The results of measuring RF radiation from 24 base stations in the Capital Governorate.

#	Town	Address	Operator	Distance	Frequency Band	Freq. (MHz)	dBm	Power Density ($\mu W/m^2$)	E-Field (V/m)	H-Field (mA/m)	% of ICNIRP Limits	% of PCPMREW Limit
CM 19	Al Nabih Saleh	---	Batelco	188 m	GSM 900	949	-19	549.49	0.455	1.208	1.07	0.5495
					GSM 1800	1878	-44	6.47	0.049	0.131	0.08	0.0065
					UMTS	2128	-47	3.94	0.039	0.102		0.0039
CM 20	Karbabad	---	Batelco	195 m	GSM 900	947	-16	974.71	0.606	1.609	1.43	0.9747
					GSM 1800	1866	-30	154.15	0.241	0.640	0.40	0.1542
					UMTS	2128	-35	57.73	0.147	0.391	0.24	0.0577
CM 21	Salmania-2	Building: 95 Road: 905 Block: 309	Batelco	148 m	GSM 900	947	-22	233.35	0.297	0.787	0.70	0.2334
					GSM 1800	1866	-46	3.78	0.038	0.100	0.06	0.0038
					UMTS	2128	-43	9.52	0.060	0.159	0.09	0.0095
CM 22	Ras Al Rumman-1	Road: 601 Block: 306	Batelco	78 m	GSM 900	951	-18	572.06	0.464	1.232	1.09	0.5721
					GSM 1800	1808	-50	1.50	0.024	0.063	0.04	0.0015
					UMTS	2128	-45	6.64	0.050	0.133	0.08	0.0066
CM 23	Ras Al Rumman-2	Road: 649 Block: 306	MTC	105 m	GSM 900	956	-13	2190	0.909	2.412	2.13	2.1900
					GSM 1800	1806-22	-22	907.99	0.585	1.553	1.00	0.9080
					UMTS	2112	-25	647.39	0.494	1.311	0.80	0.6474
CM 24	Manama	Sh. Isa Avenue Block: 307	Batelco	135 m	GSM 900	947	-19	522.98	0,444	1.178	1.04	0.5230
					GSM 1800	1869	-46	3.95	0.039	0.102	3.95	0.0040
					UMTS	2127	-40	21.94	0.091	0.241	0.14	0.0219

* Note that % of ICNIRP limit in this table is calculated by the spectrum analyser and it is not same as limit issued by ICNIRP (see section 3.1)



Figure 5.3: The map for the locations of the 16 base stations that was measured at the Northern Governorate.

Table 5.3: The results of measuring RF radiation from 16 base stations in the Northern Governorate.

#	Town	Address	Operator	Distance	Frequency Band	Freq. (MHz)	dBm	Power Density ($\mu W/m^2$)	E-Field (V/m)	H-Field (mA/m)	% of ICNIRP Limits	% of PCPMREW Limit
N1	Magsha	Road: 5037 Block: 450	Batelco	217 m	GSM 900 GSM 1800 UMTS	944 1819 2112	-23 -39 -54	181.69 19.64 0.7867	0.262 0.086 0.017	0.695 0.228 0.046	0.61 0.14 0.02	0.1817 0.0196 0.0008
N2	Barbar-1	Hous: 533 Road: 2618 Block: 526	MTC	182 m	GSM 900 GSM 1800 UMTS	959 1818 2114	-21 -31 -36	324.32 110.88 45.08	0.35 0.204 0.130	0.928 0.543 0.346	0.82 0.34 0.21	0.3243 0.1109 0.0451
N3	Barbar-2	House: 219 Barbar Avnu. Block: 524	Batelco	195 m	GSM 900 GSM 1800 UMTS	945 1874 2112	-24 -32 -55	154.58 101.77 0.6860	0.241 0.196 0.016	0.641 0.520 0.043	0.57 0.32 0.02	0.1546 0.1018 0.0007
N4	Budayyi	House:343 Road: 521 Block: 552	Batelco	154 m	GSM 900 GSM 1800 UMTS	947 No 2127	-21 Signal -47	300.25 3.90	0.336 0.038	0.893 0.102	0.79 0.06	0.3003 0.0039
N5	Maqabah	House:795 Road: 923 Block: 509	Batelco	83 m	GSM 900 GSM 1800 UMTS	946 1872 2127	-25 -67 -49	122.04 0.0281 2.26	0.214 0.003 0.029	0.569 0.009 0.078	0.5 0.00 0.04	0.1220 0.0000 0.0023
N6	Buri	Building: 586 Road: 5427 Block: 754	MTC	223 m	GSM 900 GSM 1800 UMTS	954 1864 2112	-18 -46 -33	644.45 3.67 95.37	0.493 0.037 0.190	1.308 0.099 0.503	1.15 0.06 0.31	0.6445 0.0037 0.0954
N7	Hamad Town-R.1	House:2271 Road: 331 Block: 1203	Batelco	117 m	GSM 900 GSM 1800 UMTS	948 1866 2128	-16 -37 -47	985.63 31.34 3.75	0.609 0.109 0.038	1.618 0.288 0.100	1.43 0.18 0.06	0.9856 0.0313 0.0038
N8	Dumistan	House:1739 Road: 1915 Block: 1019	Batelco	298 m	GSM 900 GSM 1800 UMTS	944 1880 2128	-20 -48 -36	372.32 2.47 50.81	0.375 0.031 0.138	0.994 0.081 0.367	0.88 0.05 0.22	0.3723 0.0025 0.0508
N9	Hamad Town-R.9	House:1462 Road: 921 Block: 1209	Batelco	140 m	GSM 900 GSM 1800 UMTS	944 1877 2128	-18 -50 -45	571.44 1.50 5.75	0.464 0.024 0.047	1.232 0.063 0.124	1.09 0.04 0.07	0.5714 0.0015 0.0058

* Note that % of ICNIRP limit in this table is calculated by the spectrum analyser and it is not same as limit issued by ICNIRP (see section 3.1)

Continued Table 5.3: The results of measuring RF radiation from 16 base stations in the Northern Governorate.

#	Town	Address	Operator	Distance	Frequency Band	Freq. (MHz)	dBm	Power Density ($\mu W/m^2$)	E-Field (V/m)	H-Field (mA/m)	% of ICNIRP Limits	% of PCPMREW Limit
N10	Hamad Town-R.17	House: 3003 Road: 1148 Block: 1211	MTC	182 m	GSM 900	930	-16	963.43	0.602	1.599	1.43	0.9634
					GSM 1800	1861	-42	8.89	0.058	0.154	0.09	0.0089
					UMTS	2112	-32	111.89	0.205	0.545	0.33	0.1119
N11	Hamad Town-R.20	Road: 1451 Block: 1214	Batelco	170 m	GSM 900	948	-18	703.00	0.515	1.366	1.21	0.7030
					GSM 1800	1864	-41	10.88	0.064	0.170	0.10	0.0109
					UMTS	2128	-37	36.17	0.117	0.310	0.19	0.0362
N12	Bu Quwwa	Road: 5547 Block: 455	Batelco	280 m	GSM 900	950	-20	430.71	0.403	1.069	0.95	0.4307
					GSM 1800	1878	-63	0.08218	0.006	0.015	0.00	0.0000
					UMTS	2128	-37	44.29	0.129	0.343	0.21	0.0443
N13	Jidhafs	Road: 2579 Block: 425	Batelco	126 m	GSM 900	942	-18	669.57	0.502	1.333	1.18	0.6696
					GSM 1800	1861	-35	50.96	0.139	0.368	0.23	0.0510
					UMTS	2142	-61	0.1445	0.007	0.020	0.01	0.0001
N14	Al Janabiya	Avenue: 77 Block: 577	MTC	340 m	GSM 900	958	-22	281.48	0.326	0.864	0.76	0.2815
					GSM 1800	1856	-39	19.14	0.082	0.225	0.14	0.0191
					UMTS	2112	-34	76.59	0.170	0.451	0.27	0.0766
N15	Sar	Building:2271 Avenue: 737 Block: 507	MTC	282 m	GSM 900	954	-19	537.09	0.450	1.194	1.05	0.5371
					GSM 1800	1861	-50	1.57	0.024	0.065	0.04	0.0016
					UMTS	2111	-41	17.43	0.081	0.215	0.13	0.0174
N16	Al Duraz	Building: 159 Avenue: 36 Block: 542	MTC	208m	GSM 900	956	-21	299.91	0.336	0.892	0.79	0.2999
					GSM 1800	1818	-30	142.09	0.231	0.614	0.39	0.1421
					UMTS	2112	-27	355.20	0.366	0.971	0.59	0.3552

* Note that % of ICNIRP limit in this table is calculated by the spectrum analyser and it is not same as limit issued by ICNIRP (see section 3.1)



Figure 5.4: The map for the locations of the 16 base stations that was measured at the Central Governorate.

Table 5.4: The results of measuring RF radiation from 16 base stations in the Central Governorate.

#	Town	Address	Operator	Distance	Frequency Band	Freq. (MHz)	dBm	Power Density ($\mu W/m^2$)	E-Field (V/m)	H-Field (mA/m)	% of ICNIRP Limits	% of PCPMREW Limit
C1	Isa Town-1	House: 7126 Road: 201 Block: 802	Batelco	171 m	GSM 900 GSM 1800 UMTS	953 1874 2128	-40 -37 -62	4.39 31.75 0.1268	0.041 0.110 0.007	0.108 0.291 0.018	0.09 0.18 0.01	0.0044 0.0318 0.0001
C2	Isa Town-2	Isa Town Mall Road: 1012 Block: 810	Batelco	75 m	GSM 900 GSM 1800 UMTS	946 1864 2112	-19 -41 -61	500.12 11.14 0.1599	0.434 0.065 0.008	1.152 0.172 0.021	1.02 0.10 0.01	0.5001 0.0111 0.0002
C3	Isa Town-3	House: 2145 Road: 2958 Block: 729	MTC	221 m	GSM 900 GSM 1800 UMTS	954 1816 2112	-18 -32 -42	604.86 100.13 13.85	0.477 0.194 0.072	1.267 0.516 0.192	1.12 0.33 0.11	0.6049 0.1001 0.0139
C4	Sitra-1	House: 1594 Road: 407 Block: 604	MTC	187 m	GSM 900 GSM 1800 UMTS	955 1853 2114	-21 -34 -36	328.22 54.04 46.96	0.352 0.143 0.133	0.933 0.379 0.353	0.82 0.24 0.21	0.3282 0.0540 0.0470
C5	Sitra-2	House: 3351 Road: 456 Block: 604	Batelco	179 m	GSM 900 GSM 1800 UMTS	948 1867 2128	-22 -45 -29	278.56 4.91 274.12	0.324 0.043 0.321	0.860 0.114 0.853	0.76 0.07 0.52	0.2786 0.0049 0.2741
C6	Sitra-3	Avenue 1 Block: 608	MTC	358 m	GSM 900 GSM 1800 UMTS	931 1808 2112	-27 -36 -44	82.63 38.89 8.73	0.176 0.121 0.057	0.468 0.321 0.152	0.42 0.20 0.09	0.0826 0.0389 0.0087
C7	Nwaidrat	House: 1301 Lane: 4324 Block: 643	Batelco	165 m	GSM 900 GSM 1800 UMTS	946 1875 No	-18 -57 signal	686.53 0.3119	0.509 0.011	1.350 0.029	1.20 0.01	0.6865 0.0003 0.0000
C8	Salmabad	Road: 437 Block: 704	Batelco	242 m	GSM 900 GSM 1800 UMTS	942 1864 2128	-17 -39 -39	760.48 18.61 22.84	0.535 0.084 0.093	1.421 0.222 0.246	1.26 0.14 0.15	0.7605 0.0186 0.0228
C9	A'ali-1	House: 1388 Road: 4036 Block: 740	Batelco	266 m	GSM 900 GSM 1800 UMTS	934 1870 2127	-34 -39 -52	14.18 20.76 1.16	0.073 0.088 0.021	0.194 0.235 0.056	0.17 0.14 0.03	0.0142 0.0208 0.0012

* Note that % of ICNIRP limit in this table is calculated by the spectrum analyser and it is not same as limit issued by ICNIRP (see section 3.1)

Continued Table 5.4: The results of measuring RF radiation from 16 base stations in the Central Governorate.

#	Town	Address	Operator	Distance	Frequency Band	Freq. (MHz)	dBm	Power Density ($\mu W/m^2$)	E-Field (V/m)	H-Field (mA/m)	% of ICNIRP Limits	% of PCPMREW Limit
C10	A'ali-2	House: 970 Road: 3426 Block:	MTC	245 m	GSM 900 GSM 1800 UMTS	953 1861 2114	-21 -38 -32	335.01 27.09 125.87	0.355 0.101 0.218	0.943 0.268 0.578	0.83 0.17 0.35	0.3350 0.0271 0.1259
C11	Sanad	House: 1692 Road: 4349 Block: 743	MTC	190 m	GSM 900 GSM 1800 UMTS	926 1864 2128	-18 -41 -37	673.36 10.88 36.17	0.515 0.064 0.117	1.366 0.170 0.310	1.21 0.10 0.19	0.6734 0.0109 0.0362
C12	Bukawara-1	---	MTC	240 m	GSM 900 GSM 1800 UMTS	955 1816 2111	-23 -41 -35	182.47 11.70 69.78	0.262 0.066 0.162	0.696 0.176 0.430	0.61 0.11 0.26	0.1825 0.0117 0.0698
C13	Bukawara-2	---	Batelco	161 m	GSM 900 GSM 1800 UMTS	943 1866 2128	-20 -35 -43	367.84 45.34 9.16	0.372 0.131 0.059	0.988 0.347 0.156	0.88 0.22 0.09	0.3678 0.0453 0.0092
C14	Buhair	---	Batelco	171 m	GSM 900 GSM 1800 UMTS	946 1872 2128	-19 -40 -45	537.45 14.70 5.78	0.450 0.74 0.047	1.195 0.198 0.124	1.06 0.12 0.07	0.5375 0.0147 0.0058
C15	Hajiat	---	Batelco	144 m	GSM 900 GSM 1800 UMTS	950 1875 2112	-18 -52 -49	575.97 1.06 2.31	0.466 0.020 0.030	1.237 0.053 0.078	1.09 0.03 0.04	0.5760 0.0011 0.0023
C16	Jid Ali	---	Batelco	196 m	GSM 900 GSM 1800 UMTS	950 1864 2128	-23 -33 -40	213.45 82.02 20.91	0.284 0.176 0.088	0.752 0.466 0.236	0.66 0.29 0.14	0.2135 0.0820 0.0209

* Note that % of ICNIRP limit in this table is calculated by the spectrum analyser and it is not same as limit issued by ICNIRP (see section 3.1)

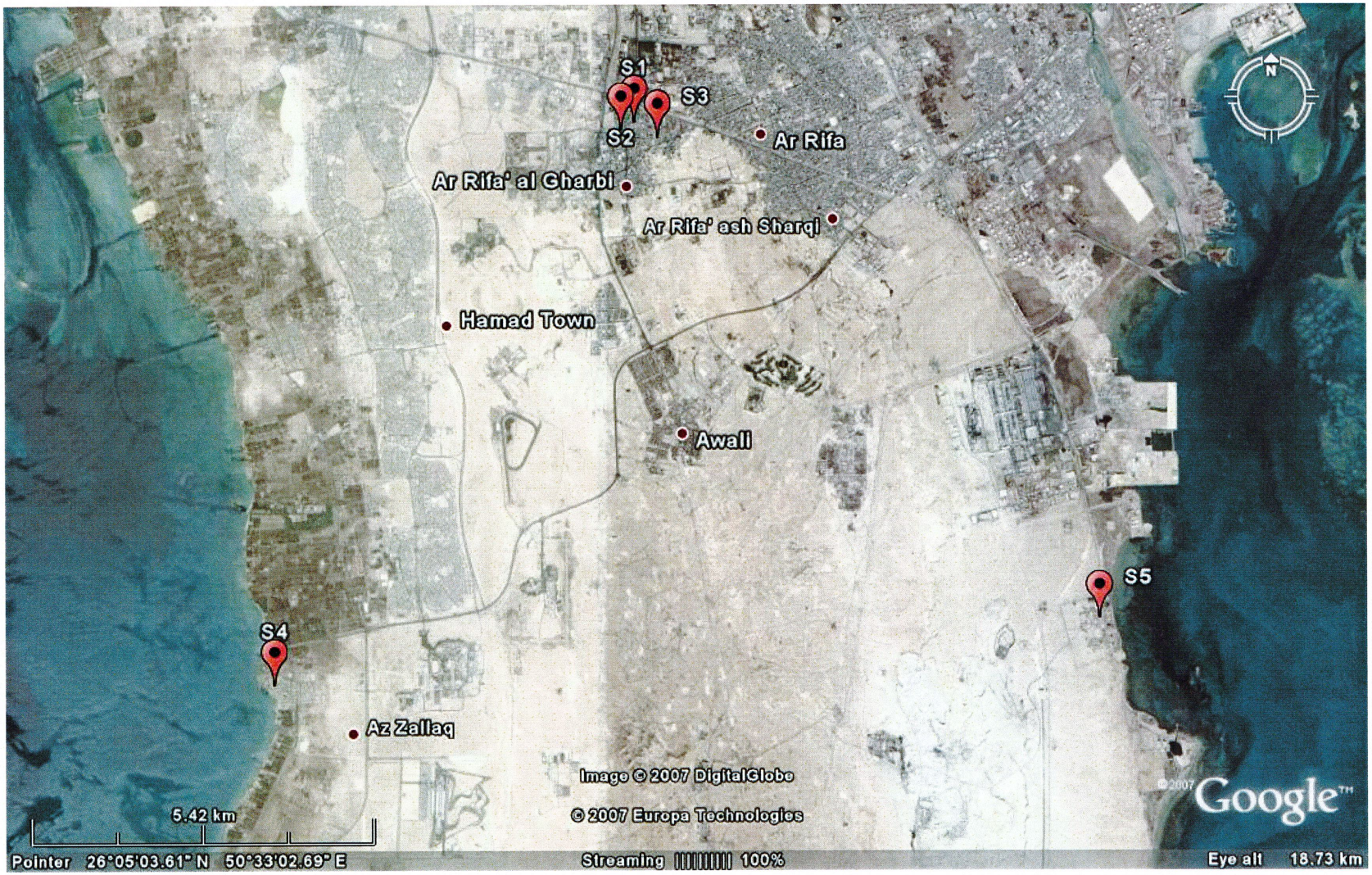


Figure 5.5: The map for the locations of the 16 base stations that was measured at the Southern Governorate.

Table 5.5: The results of measuring RF radiation from 16 base stations in the Southern Governorate.

#	Town	Address	Operator	Distance	Frequency Band	Freq. (MHz)	dBm	Power $\mu W/m^2$	E-Field V/m	H-Field mA/m	% of ICNIRP Limits	% of PCPMREW Limit
S1	West Riffa-1	House: 190 Road: 1204 Block: 912	MTC	189 m	GSM 900 GSM 1800 UMTS	956 1811 2115	-19 -34 -30	516.25 62.62 169.25	0.441 0.154 0.272	1.171 0.408 0.722	1.03 0.26 0.44	0.5163 0.0626 0.1693
S2	West Riffa-2	House: 1571 Road: 1249 Block: 912	Batelco	94 m	GSM 900 GSM 1800 UMTS	950 1870 2128	-27 -44 -49	81.24 6.86 2.69	0.175 0.051 0.032	0.464 0.135 0.085	0.41 0.08 0.05	0.0812 0.0069 0.0027
S3	West Riffa-3	House: 734 Road: 426 Block: 904	Batelco	254 m	GSM 900 GSM 1800 UMTS	946 1864 2112	-26 -52 -68	92.20 0.927 0.0308	0.186 0.019 0.003	0.495 0.050 0.090	0.44 0.03 0.00	0.0922 0.0009 0.0000
S4	Al Zalaq	House: 302 Road: 5709 Block: 1057	Batelco	139 m	GSM 900 GSM 1800 UMTS	959 1819 2114	-14 -55 -46	1530 0.492 4.72	0.760 0.014 0.042	2.016 0.036 0.112	1.78 0.02 0.06	1.5300 0.0005 0.0048
S5	Askar	House: 346 Road: 5011 Block: 950	MTC	288 m	GSM 900 GSM 1800 UMTS	954 1805 2114	-30 -65 -46	38.25 0.0477 5.23	0.121 0.004 0.044	0.318 0.011 0.118	0.28 0.00 0.07	0.0383 0.0000 0.0052

* Note that % of ICNIRP limit in this table is calculated by the spectrum analyser and it is not same as limit issued by ICNIRP (see section 3.1)

Discussion the results for Al Muharraq Governorate:

The results for this Governorate, from table 5.1, are graphed in Figure 5.6. The Maximum, Minimum, and Average values of RF radiation for the three bands, GSM900, GSM1800 and UMTS, for this Governorate were summarized in Table 5.6 and graphed in Figure 5.7.

The highest level of RF radiation in Al Muharraq Governorate for the nine base stations was found in Al Hidd (site no.1) at Hatim Altaie Avenue, Block 110 at distance 169 m from the base station. This base station is operated by MTC. The frequency of RF radiation was 957 MHz (GSM900 band) and its power density was 1800 $\mu W/m^2$ (**E** = 0.825 V/m and **H** = 2.190 mA/m). However, this value is less than ICNIRP limit by 2572 times or 0.039% of that limit and less than PCPMREW limit by 56 or 1.8% of that limit.

The results for GSM1800 and UMTS bands were much less than GSM900 band. The highest value of power density of RF radiation for GSM1800 band was 313.37 $\mu W/m^2$ (**E** = 0.344 V/m and **H** = 0.912 mA/m) and for UMTS band was 116.28 $\mu W/m^2$ (**E** = 0.209 V/m and **H** = 0.556 mA/m). These values are about 0.0035% and 0.0012% of ICNIRP limit respectively, and 0.313% and 0.116% of PCPMREW limit respectively.

The overall average power density for the nine base stations under survey in this Governorate was 697.19 $\mu W/m^2$ for the band of GSM900, 72.83 $\mu W/m^2$ for the band of GSM1800 and 28.65 $\mu W/m^2$ for the band of UMTS. The percentages of these averages for each band relative to ICNIRP limit and relative to PCPMREW limit are as follow:

- For GSM900: The average (697.19 $\mu W/m^2$) is about 0.015 % of ICNIRP limit and about 0.697% of PCPMREW limit
- For GSM1800: The average (72.83 $\mu W/m^2$) is about 0.00081% of ICNIRP limit and about 0.073% of PCPMREW limit
- For UMTS: The average (28.65 $\mu W/m^2$) is about 0.00029% of ICNIRP limit and about 0.029% of PCPMREW limit

We notice clearly that all RF radiation from the base stations at three bands are much less than both exposure limits, ICNIRP and PCPMREW. This radiation does not exceed 0.04% of ICNIRP limits and do not exceed 2% of PCPMREW limits. Also we can notice that the levels of RF radiation in the bands of GSM1800 and UMTS were several times lower than that of GSM900 band.

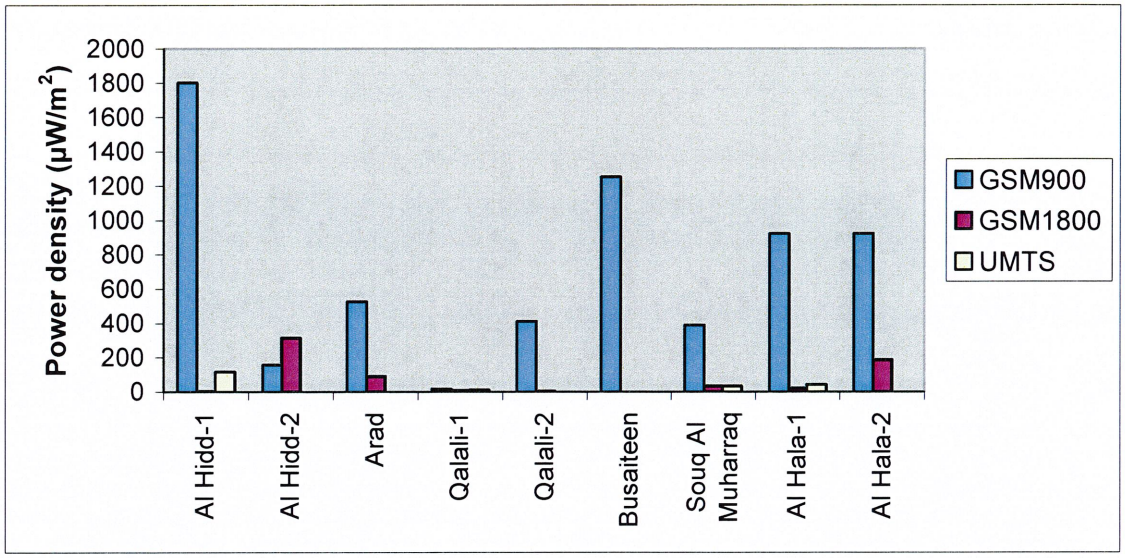


Figure 5.6: Graph of Al Muharraq Governorate results.

Table 5.6: Maximum, Minimum, and Average for Al Muharraq Governorate results.

	Frequency Band	Town	dBm	Power density ($\mu W/m^2$)	E-Field (V/m)	H-Field (mA/m)	% of ICNIRP limit	% of PCPMREW limit
Maximum	GSM900	Al Hidd-1	-14	1800	0.825	2.190	1.93	1.8000
	GSM 1800	Al Hidd-2	-27	313.37	0.344	0.912	0.57	0.3134
	UMTS	Al Hidd-1	-32	116.28	0.209	0.556	0.34	0.1163
Minimum	GSM900	Qalali-1	-34	15.73	0.077	0.204	0.17	0.0157
	GSM 1800	Busaiteen	-54	0.588	0.015	0.04	0.02	0.0006
	UMTS	Al Hidd-2	-63	0.109	0.006	0.017	0.01	0.0001
Average	GSM900	----	-20	697.19	0.466	1.237	1.09	0.6972
	GSM 1800	----	-39	72.83	0.125	0.333	0.21	0.0728
	UMTS	----	-43	28.65	0.076	0.203	0.12	0.0287

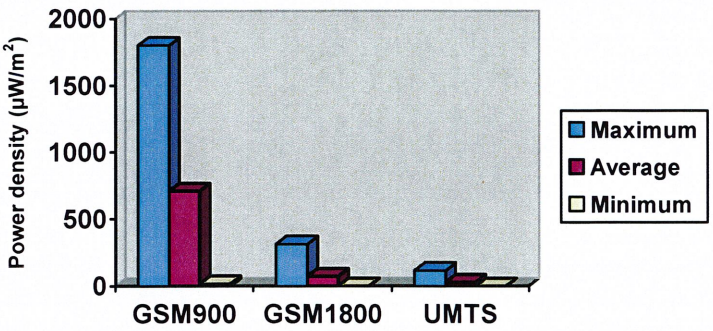


Figure 5.7: Graph of maximum, minimum and average for the three network bands at Al Muharraq Governorate.

Discussion the results for the Capital Governorate:

The results for this Governorate, from Table 5.2, are graphed in Figure 5.8. The Maximum, Minimum, and Average values of RF radiation for the three bands, GSM900, GSM1800 and UMTS, for this Governorate were summarized in Table 5.7 and graphed in Figure 5.9.

The highest level of RF radiation in the Capital Governorate (twenty four base stations) was found in Sanabis at Road 812, Block 408 - at distance 122 m from the base station. This base station is operated by MTC. The frequency of RF radiation is 956 MHz and the recorded power density was 3400 $\mu W/m^2$ (**E** = 1.133 V/m and **H** = 3.007 mA/m). This value is less than ICNIRP limit by 1362 times (0.073% of this limit) and less is than PCPMREW limit by 29 times (3.400% of this limit). This value of power density, 3400 $\mu W/m^2$, is also the highest RF radiation level recorded in this survey (among 70 base stations). It is almost 4 times greater than the average recorded value for the Capital governorate (883.93 $\mu W/m^2$) or almost 6 times greater than the overall average (577.64 $\mu W/m^2$) for the five governorates in the band of GSM900.

Meanwhile, the lowest recorded power density in the Capital governorate (104.40 $\mu W/m^2$) –in Mahooz– is almost 33 times less than the highest recorded value which was 3400 $\mu W/m^2$ in Sanabis. This shows that there are big variations of RF radiations levels between highest and lowest values of power density. However these variations represent less than 0.1% of ICNIRP limit.

This relatively high value (in Block 408 in Sanabis) can be attributed to many reasons. The first reason may be attributed to a possibility of the rating power of the used transmitter in this location. It may be larger than the others. The power of each base station transmitter is set to a level that allows a mobile phone to be used within the area for which the base station is designed to provide coverage, but not outside the coverage area. Higher powers are needed to cover larger cells or area and also to cover cells with difficult ground terrain. Unfortunately, we failed to obtain information from MTC in this regards. Instead of that we can compare the distances between each base station and surrounding base stations to know the coverage area. We found that Sanabis base station has larger distances between it and the three surrounding base stations than other MTC base stations and the three base stations surrounding each one. This means that Sanabis base station has more power to cover larger area. Moreover, there are no base stations in the area from the base station to the coast which locate at distance of about

1.6 km to the north. This value is about twice the distances between MTC base stations. In this area our measurement was taken. This observation supports our justification.

The second reason may be attributed to the larger capacity of the base stations, i.e. having multiple transmitters; the output power can vary over time and with the number of calls being handled. One of the transmitters -in this case- is expected to transmit RF radiation continuously at full power, whereas the other transmitters will operate intermittently and with varying power levels up to the maximum. As an example, the power output of a macrocellular base station with 10 W transmitters could vary between a minimum of 10 W and a maximum of 100 W over time.

The results for GSM1800 band and UMTS were much less than GSM900 band. The highest value of power density of RF radiation for GSM1800 also was found in Sanabis and it was 1440 $\mu W/m^2$ (**E** = 0.737 V/m and **H** = 1.958 mA/m). For UMTS band, the highest value of power density was 647.39 $\mu W/m^2$ (**E** = 0.494 V/m and **H** = 1.311 mA/m) and was found in Ras Al Rumman (site 2). These values are about 0.016% and 0.0065% of ICNIRP limit respectively, and 1.440% and 0.647% of PCPMREW limit respectively.

The average power density for the twenty four base stations under survey in this Governorate was 883.93 $\mu W/m^2$ for the band of GSM900, 200.92 $\mu W/m^2$ for the band of GSM1800 and 59.51 $\mu W/m^2$ for the band of UMTS. The percentages of the averages for each band relative to ICNIRP limit and relative to PCPMREW limit are as follow:

- For GSM900: The average (883.93 $\mu W/m^2$) is about 0.019% of ICNIRP limit and about 0.884% of PCPMREW limit.
- For GSM1800: The average (200.92 $\mu W/m^2$) is about 0.0022% of ICNIRP limit and about 0.201% of PCPMREW limit.
- For UMTS: The average (59.51 $\mu W/m^2$) is about 0.00060% of ICNIRP limit and about 0.060% of PCPMREW limit.

Therefore all RF radiation from the base stations are much less than both exposure limits, ICNIRP and PCPMREW. This radiation does not exceed 0.08% of ICNIRP limits and do not exceed 3.4% of PCPMREW limits. We can notice clearly that the levels of RF radiation in the bands of GSM1800 and UMTS were several times lower than that of GSM900 band and insignificant.

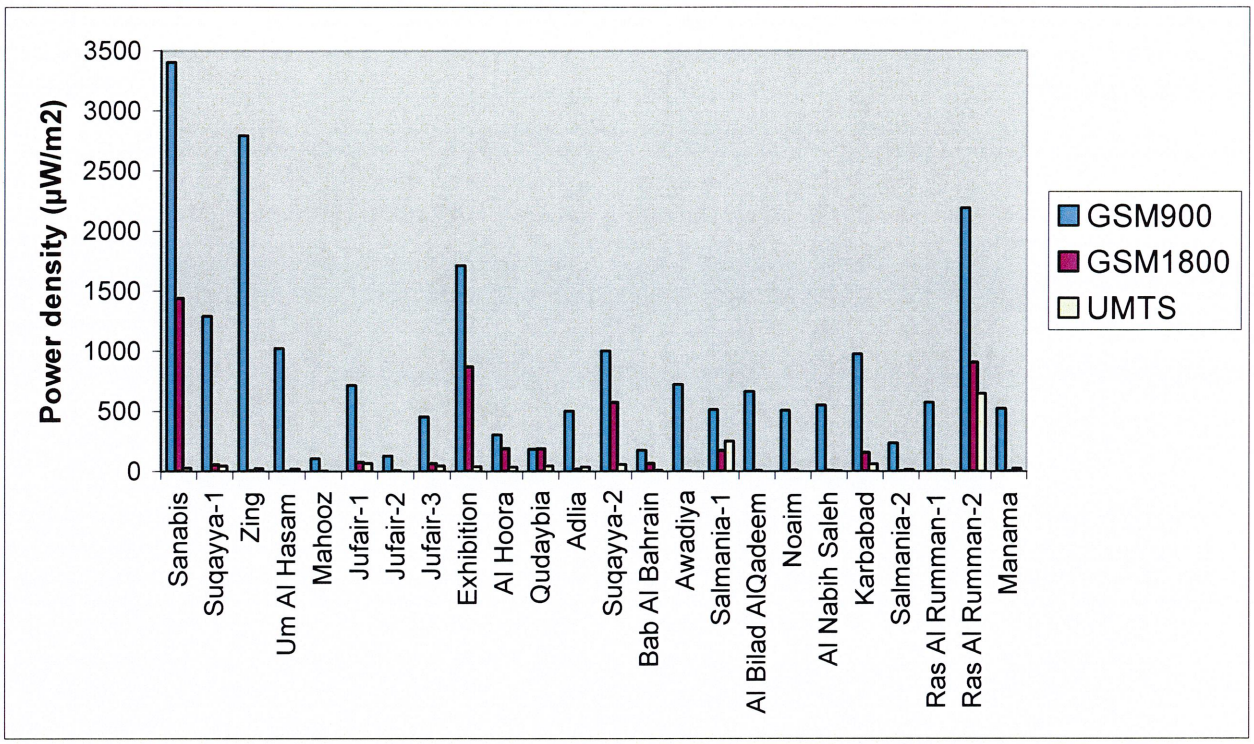


Figure 5.8: Graph of the Capital Governorate results.

Table 5.7: Maximum, Minimum, and Average for the Capital Governorate.

	Frequency Band	Town	dBm	Power density ($\mu W/m^2$)	E-Field (V/m)	H-Field (mA/m)	% of ICNIRP limit	% of PCPMREW limit
Maximum	GSM900	Sanabis	-11	3400	1.133	3.007	2.66	3.4000
	GSM1800	Sanabis	-20	1440	0.737	1.958	3.95	1.4400
	UMTS	Ras Al R.-2	-25	647.39	0.494	1.311	0.80	0.6474
Minimum	GSM900	Mahooz	-26	104.40	0.198	0.526	0.46	0.1044
	GSM1800	Um Al H.	-50	1.49	0.024	0.063	0.007	0.0015
	UMTS	Jufair-2	-65	0.069	0.005	0.014	0.000	0.0000
Average	GSM900	----	-18	883.93	0.529	1.395	1.23	0.8839
	GSM1800	----	-37	200.92	0.200	0.500	0.47	0.2009
	UMTS	----	-42	59.51	0.109	0.289	0.18	0.0595

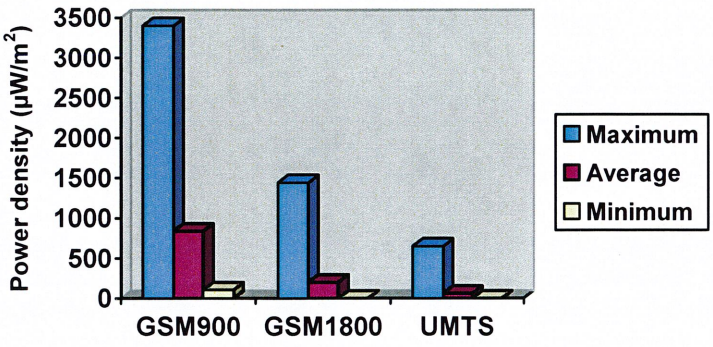


Figure 5.9: Graph of maximum, minimum and average for the three network bands at the Capital Governorate.

Discussion the results for the Northern Governorate:

The results for this Governorate, from Table 5.3, are graphed in Figure 5.10. The Maximum, Minimum, and Average values of RF radiation for the three bands, GSM900, GSM1800 and UMTS, for this Governorate were summarized in Table 5.8 and graphed in Figure 5.11.

The highest level of RF radiation in the Northern Governorate for the 16 base stations was found in Hamad Town (roundabout 1) near House: 2271, Road: 331, Block: 1203 at distance 117m from the base station. This base station is operated by Batelco. The frequency of RF radiation was 948 MHz and its power density was 985.63 $\mu W/m^2$ (**E** = 0.609 V/m and **H** = 1.618 mA/m). However, this value is less than ICNIRP limit by 4697 times or 0.021% of that limit and less than PCPMREW limit by 101 or 0.986% of that limit.

The results for GSM1800 band and UMTS were much less than GSM900 band. The highest value of power density of RF radiation for GSM1800 band was found in Al Duraz and it was 142.09 $\mu W/m^2$ (**E** = 0.231 V/m and **H** = 0.614 mA/m) and for UMTS it was also found in Al Duraz and it was 355.2 $\mu W/m^2$ (**E** = 0.366 V/m and **H** = 0.971 mA/m). These values are about 0.0016% and 0.0036% of ICNIRP limit respectively, and 0.142% and 0.355% of PCPMREW limit respectively.

The average power density for the 16 base stations under survey in this Governorate was 471.37 $\mu W/m^2$ for the band of GSM900, 33.66 $\mu W/m^2$ for the band of GSM1800 and 53.13 $\mu W/m^2$ for the band of UMTS. The percentages of the averages for each band relative to ICNIRP limit and relative to PCPMREW limit are as follow:

- For GSM900: The average (471.37 $\mu W/m^2$) is about 0.010 % of ICNIRP limit and about 0.471% of PCPMREW limit
- For GSM1800: The average (33.66 $\mu W/m^2$) is about 0.00037% of ICNIRP limit and about 0.034% of PCPMREW limit
- For UMTS: The average (53.13 $\mu W/m^2$) is about 0.00053% of ICNIRP limit and about 0.053% of PCPMREW limit

We notice clearly that all RF radiation from the base stations at three bands are much less than both exposure limits, ICNIRP and PCPMREW. This radiation does not exceed 0.021% of ICNIRP limits and do not exceed 1% of PCPMREW limits. Also we can notice that the levels of RF radiation in the bands of GSM1800 and UMTS were several times lower than that of GSM900 band and insignificant.

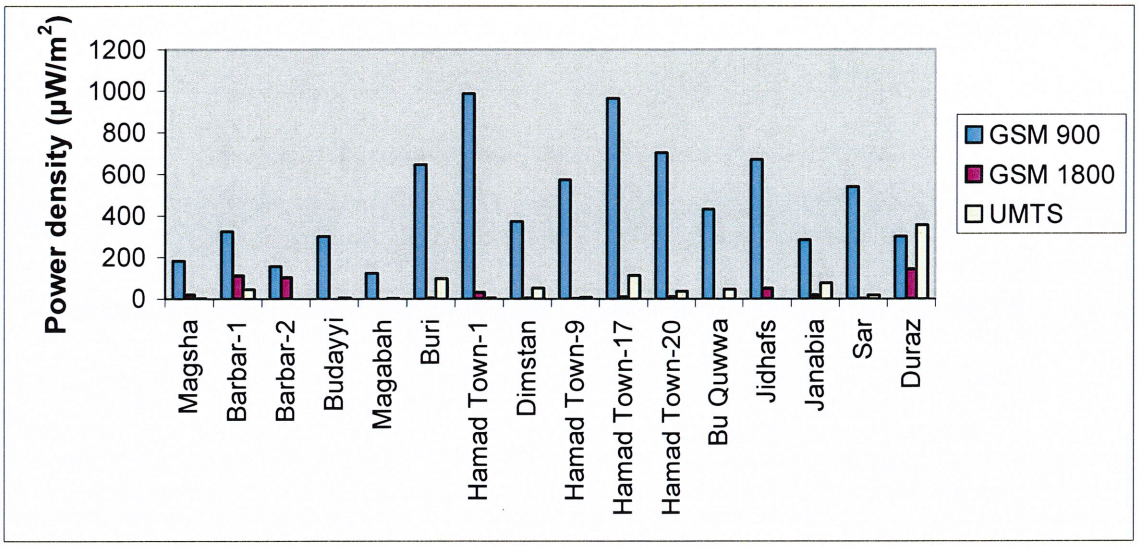


Figure 5.10: Graph of the Northern Governorate results.

Table 5.8: Maximum, Minimum, and Average for the Northern Governorate.

	Frequency Band	Town	dBm	Power density ($\mu W/m^2$)	E-Field (V/m)	H-Field (mA/m)	% of ICNIRP limit	% of PCPMREW limit
Maximum	GSM900	Hamad T.-1	- 16	985.63	0.609	1.618	1.43	0.9856
	GSM1800	Duraz	- 30	142.09	0.231	0.614	0.39	0.1421
	UMTS	Duraz	- 27	355.2	0.366	0.971	0.59	0.3552
Minimum	GSM900	Maqabah	- 25	122.04	0.214	0.569	0.50	0.1220
	GSM1800	Maqabah	- 67	0.0281	0.003	0.009	0.00	0.0000
	UMTS	Jidhafs	- 61	0.1445	0.007	0.02	0.01	0.0001
Average	GSM900	---	- 20	471.37	0.405	1.075	0.95	0.4714
	GSM1800	---	- 43	33.66	0.086	0.229	0.14	0.0337
	UMTS	---	- 42	53.13	0.107	0.285	0.17	0.0531

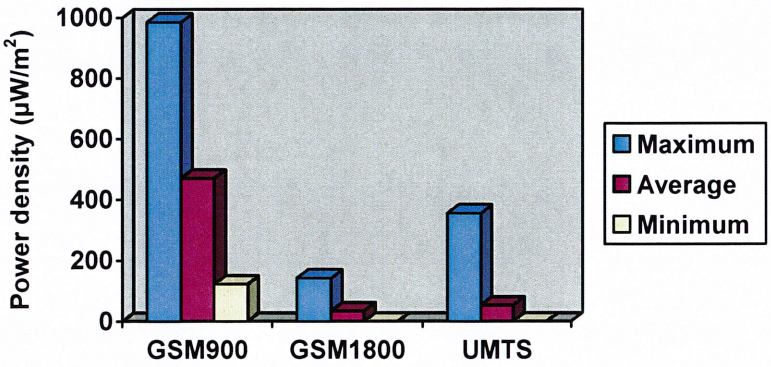


Figure 5.11: Graph of maximum, minimum and average for the three network bands at the Northern Governorate.

Discussion the results for the Central Governorate:

The results for this Governorate, from Table 5.4, are graphed in Figure 5.12. The Maximum, Minimum, and Average values of RF radiation for the three bands, GSM900, GSM1800 and UMTS, for this Governorate were summarized in Table 5.9 and graphed in Figure 5.13.

The highest level of RF radiation in the Central Governorate for the sixteen base stations was found in Salmabad at Road 437, Block 704 at distance 242 m from the base station. This base station is operated by Batelco. The frequency of RF radiation was 942 MHz (GSM900 band) and its power density was 760.48 $\mu W/m^2$ (**E** = 0.535 V/m and **H** = 1.421 mA/m). However, this value is less than ICNIRP limit by 6088 times or 0.016% of that limit and less than PCPMREW limit by 131 or 0.760% of that limit.

The results for GSM1800 band and UMTS were much less than GSM900 band. The highest value of power density of RF radiation for GSM1800 band was found in Isa Town-3 and it was 100.13 $\mu W/m^2$ (**E** = 0.194 V/m and **H** = 0.516 mA/m) and for UMTS band was found in Sitra-2 and it was 274.12 $\mu W/m^2$ (**E** = 0.321 V/m and **H** = 0.853 mA/m). These values are about 0.0011% and 0.0027% of ICNIRP limit respectively, and 0.100% and 0.274% of PCPMREW limit respectively.

The average power density for the 16 base stations under survey in this Governorate was 384.10 $\mu W/m^2$ for the band of GSM900, 29.58 $\mu W/m^2$ for the band of GSM1800 and 42.53 $\mu W/m^2$ for the band of UMTS. The percentages of these averages for each band relative to ICNIRP limit and relative to PCPMREW limit are as follow:

- For GSM900: The average (384.10 $\mu W/m^2$) is about 0.0083% of ICNIRP limit and about 0.384% of PCPMREW limit
- For GSM1800: The average (29.58 $\mu W/m^2$) is about 0.00033% of ICNIRP limit and about 0.030% of PCPMREW limit
- For UMTS: The average (42.53 $\mu W/m^2$) is about 0.00043% of ICNIRP limit and about 0.043% of PCPMREW limit

We notice clearly that all RF radiation from the base stations at three bands are much less than both exposure limits, ICNIRP and PCPMREW. This radiation does not exceed 0.02% of ICNIRP limits and do not exceed 0.8% of PCPMREW limits. Also we can notice that the levels of RF radiation in the bands of GSM1800 and UMTS were several times lower than that of GSM900 band and insignificant.

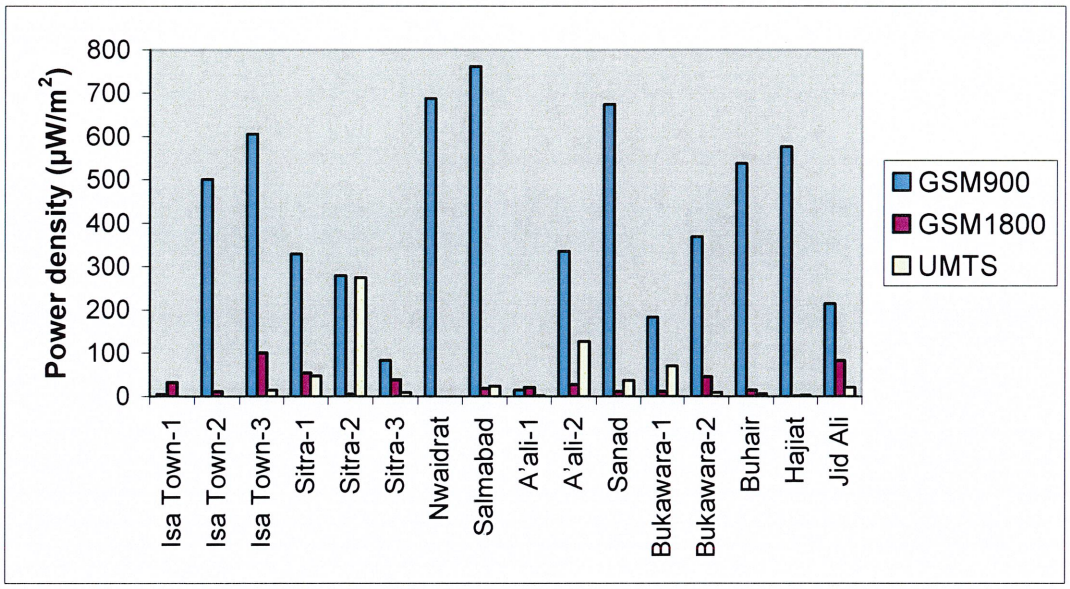


Figure 5.12: Graph of the Central Governorate results.

Table 5.9: Maximum, Minimum, and Average for the Central Governorate.

	Frequency Band	Town	dBm	Power density ($\mu W/m^2$)	E-Field (V/m)	H-Field (mA/m)	% of ICNIRP limit	% of PCPMREW limit
Maximum	GSM900	Salmabad	-17	760.48	0.535	1.421	1.26	0.760
	GSM 1800	Isa Town-3	-32	100.13	0.194	0.516	0.33	0.100
	UMTS	Sitra-2	-29	274.12	0.321	0.853	0.52	0.274
Minimum	GSM900	Isa Town-1	-40	4.39	0.041	0.108	0.09	0.0044
	GSM 1800	Nuwaidrat	-57	0.31	0.011	0.029	0.01	0.0003
	UMTS	Isa Town-1	-62	0.13	0.007	0.018	0.01	0.0001
Average	GSM900	----	-22	384.10	0.352	0.933	0.83	0.384
	GSM 1800	----	-40	29.58	0.135	0.247	0.15	0.0296
	UMTS	----	-43	42.53	0.096	0.254	0.15	0.0425

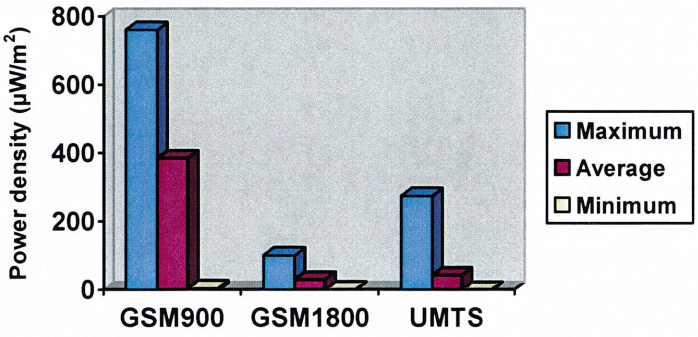


Figure 5.13: Graph of maximum, minimum and average for the three network bands at the Central Governorate.

Discussion the results for the Southern Governorate:

The results for this Governorate, from Table 5.5, are graphed in Figure 5.14. The Maximum, Minimum, and Average values of RF radiation for the three bands, GSM900, GSM1800 and UMTS, for this Governorate were summarized in Table 5.10 and graphed in Figure 5.15.

The highest level of RF radiation in Southern Governorate for the five base stations was found in Al Zalaq near house 302, Road 5709, Block 1057 at distance 139 m from the base station. This base station is operated by Batelco. The frequency of RF radiation was 959 MHz (GSM900 band) and its power density was 1530 $\mu W/m^2$ (**E** = 0.760 V/m and **H** = 2.016 mA/m). However, this value is less than ICNIRP limit by 3026 times or 0.033% of that limit and less than PCPMREW limit by 65 or 1.530% of that limit.

The results for GSM1800 band and UMTS were much less than GSM900 band. The highest value of power density of RF radiation for GSM1800 band was found in West Riffa-1 and it was 62.62 $\mu W/m^2$ (**E** = 0.154 V/m and **H** = 0.408 mA/m) and for UMTS band was 169.25 $\mu W/m^2$ (**E** = 0.272 V/m and **H** = 0.722 mA/m) and also was found in West Riffa-1. These values are about 0.00069% and 0.0017% of ICNIRP limit respectively, and 0.063% and 0.169% of PCPMREW limit respectively.

The average power density for the 9 base stations under survey in this Governorate was 451.59 $\mu W/m^2$ for the band of GSM900, 14.19 $\mu W/m^2$ for the band of GSM1800 and 36.38 $\mu W/m^2$ for the band of UMTS. The percentages of these averages for each band relative to ICNIRP limit and relative to PCPMREW limit are as follow:

- For GSM900: The average (451.59 $\mu W/m^2$) is about 0.0098% of ICNIRP limit and about 0.452% of PCPMREW limit
- For GSM1800: The average (14.19 $\mu W/m^2$) is about 0.00016% of ICNIRP limit and about 0.014% of PCPMREW limit
- For UMTS: The average (36.38 $\mu W/m^2$) is about 0.00036% of ICNIRP limit and about 0.036% of PCPMREW limit

We notice clearly that all RF radiation from the base stations at three bands are much less than both exposure limits, ICNIRP and PCPMREW. This radiation does not exceed 0.033% of ICNIRP limits and do not exceed 1.6% of PCPMREW limits. Also we can notice that the levels of RF radiation in the bands of GSM1800 and UMTS were several times lower than that of GSM900 band.

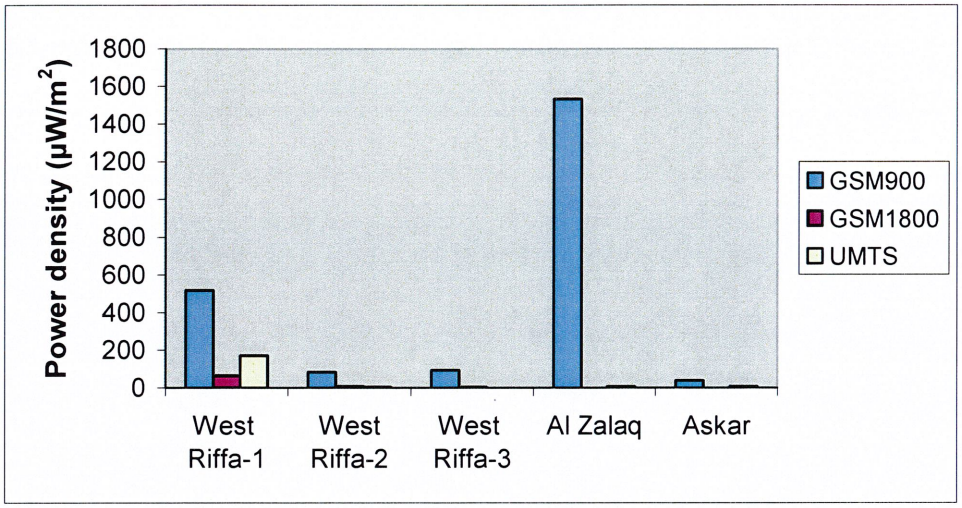


Figure 5.14: Graph of the Southern Governorate results.

Table 5.10: Maximum, Minimum, and Average for the Southern Governorate.

	Frequency Band	Town	dBm	Power density ($\mu W/m^2$)	E-Field (V/m)	H-Field (mA/m)	% of ICNIRP limit	% of PCPMREW limit
Maximum	GSM900	Al Zalaq	-14	1530	0.76	2.016	1.78	1.5300
	GSM 1800	W. Riffa-1	-34	62.62	0.154	0.408	0.26	0.0626
	UMTS	W. Riffa-1	-30	169.25	0.272	0.722	0.44	0.1693
Minimum	GSM900	Askar	-30	38.25	0.121	0.318	0.28	0.0383
	GSM 1800	Askar	-65	0.048	0.004	0.011	0.00	0.0000
	UMTS	W. Riffa-3	-68	0.031	0.003	0.085	0.00	0.0000
Average	GSM900	----	-23	451.59	0.34	0.893	0.79	0.4516
	GSM 1800	----	-50	14.19	0.05	0.128	0.08	0.0142
	UMTS	----	-48	36.38	0.08	0.225	0.12	0.0364

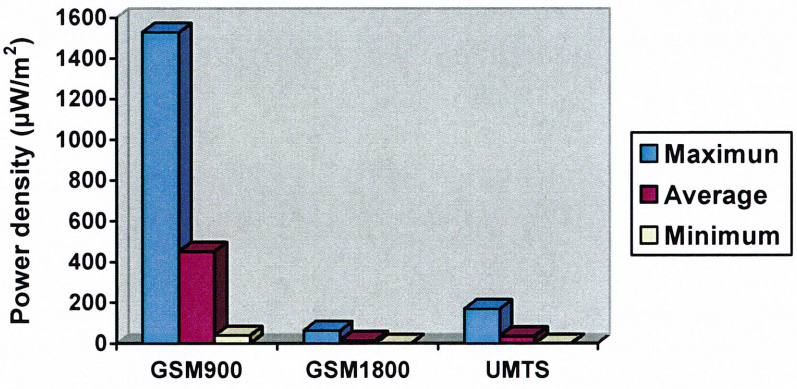


Figure 5.15: Graph of maximum, minimum and average for the three network bands at the Southern Governorate.

The following Figure illustrates the comparison of the average for the five governorates.

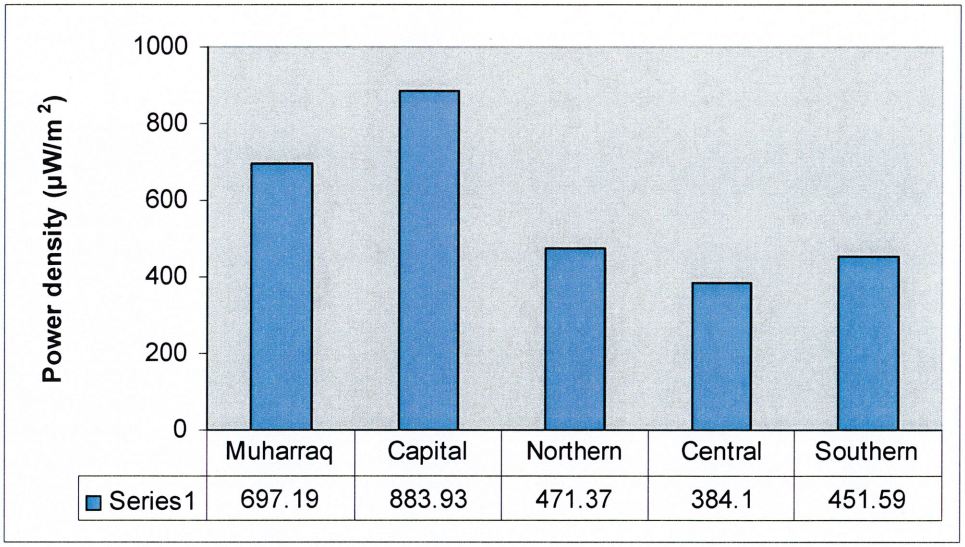


Figure 5.16: The comparison between the averages of the five Governorates for GSM900 band.

It is clearly that Capital Governorate has the highest average, 883.93 $\mu W/m^2$, and Al Muharraq Governorate has the second highest average 697.19 $\mu W/m^2$. The Central and Southern Governorates have approximate averages, 471.37 $\mu W/m^2$ and 451.59 $\mu W/m^2$ respectively, and the lowest average was in Central Governorate 384.10 $\mu W/m^2$.

The overall average for the five governorates, in term of power density, is 577.64 $\mu W/m^2$. This value is about 0.012% of ICNIRP limit and about 0.578% of PCPMREW limit.

For the GSM1800 band, the overall average of the power density for the five governorates is 70.24 $\mu W/m^2$ which represents about 0.00078% of ICNIRP limit and about 0.070% of PCPMREW limit.

For the UMTS the overall average of the power density for the five governorates average 44.04 $\mu W/m^2$ which represent about 0.00044% of ICNIRP limit and about 0.044% of PCPMREW limit.

5.2 Long Term (24 hours) Measurements of RF Radiation:

The long term measurements, 24 hours duration, was conducted for 5 base stations. These base stations are N5 at Maqabah (Northern Governorate), N13 at Jidhafs (Northern Governorate), CM20 at Ras Al Rumman (Capital Governorate), CM22 at Karbabad (Capital Governorate) and at Samaheej (Al Muharraq Governorate) (see Figures 5.1, 5.2, 5.3 and 5.4). The results obtained represented in the following Figures.

The power is represented in unit of dBm because the device saves the data from the long term measurement in this unit only. To convert this unit to $\mu W/m^2$ the following table can be used which was calculated according to our previous result. The corresponding

Table 5.11: Conversion between dBm and $\mu W/m^2$.

dBm	-14	-15	-16	-17	-18	-19	-20	-21
$\mu W/m^2$	1680	1270	978	802	650	516	394	315
dBm	-22	-23	-24	-25	-26	-27	-28	-----
$\mu W/m^2$	280	182	162	124	98	82	69.59	-----

This type of measurement gives us an idea about the variation of RF during a day. Moreover, it can shows the maximum and minimum and therefore how far between them. This can help us to know also how the result in type one of measurements, environmental measurements, could change when the measurement conducted at another time of the day.

The measurements for the five base stations were started at about 6:00 p.m. The results were rearranged to be started at 00:00 A.M. The frequency band for this type of measurements was the GSM900 band because as we notice from previous results, the GSM1800 and UMTS bands are much less in the levels of RF radiation than GSM900.

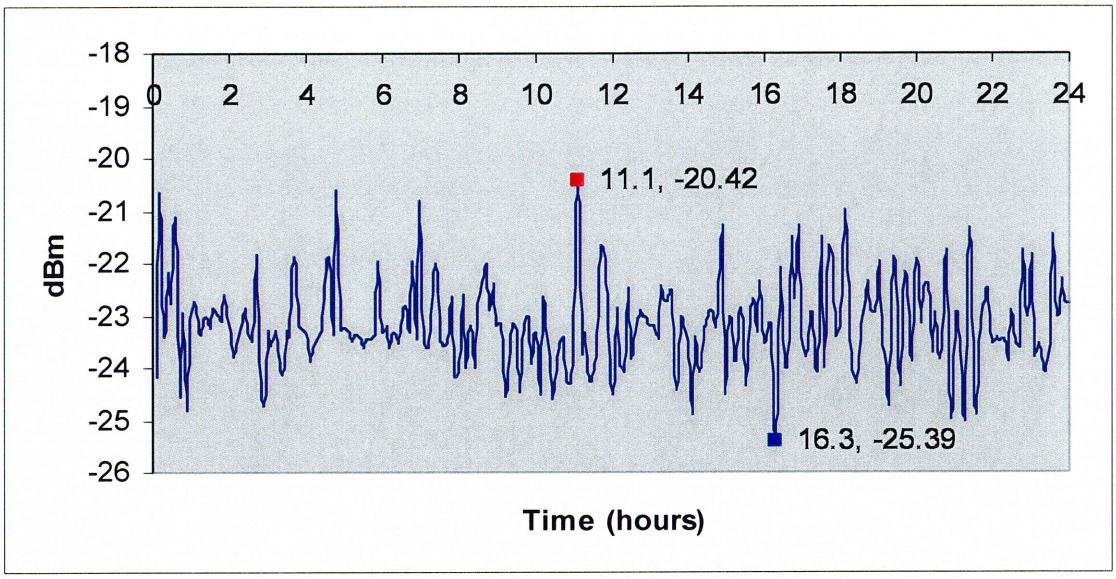


Figure 5.17: Long term measurements of RF emission from the base station in Jidhafs-N13 (Northern Governorate).

This base station sited in the middle of Jidhafs village, one of the high density population in the Northern Governorate. The measurement was conducted on the roof of 3 stories building which locates at distance 106 m from the base station. The address of this building is: House: 475, Road: 2514, Block: 425. This base station is operated by Batelco. The frequency band for measurements was GSM900.

The highest level of RF radiation was recorded at 11:06 a.m. which was -20.42dBm (about 394 $\mu W/m^2$) and the lowest level of RF radiation was recorded at 04:18 p.m. which was -25.39 dBm (about 124 $\mu W/m^2$) .The average level of RF radiation -23.1827 (182 $\mu W/m^2$).

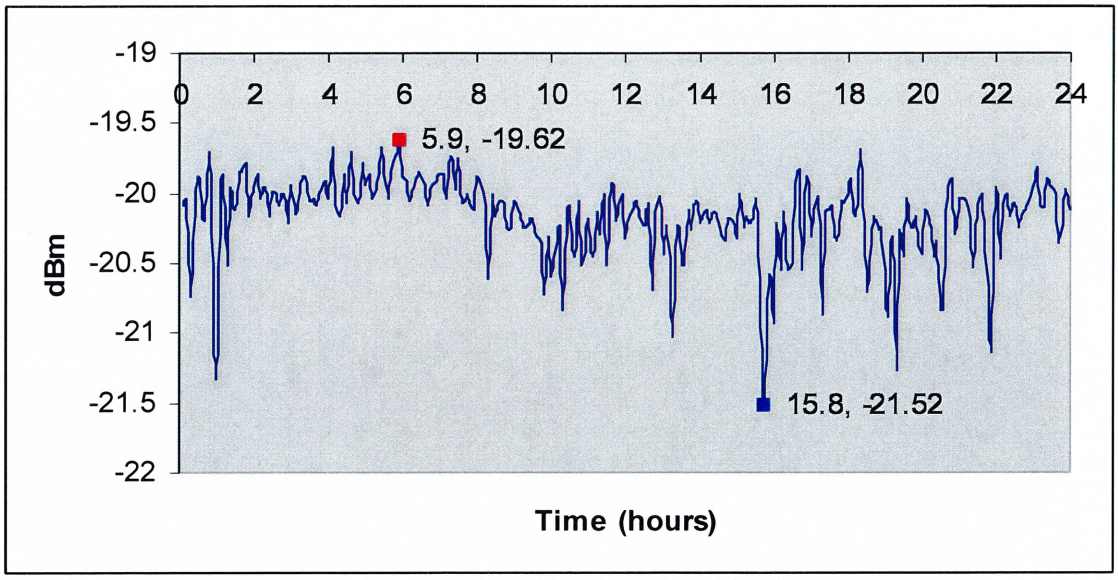


Figure 5.18: Long term measurements of RF emission from the base station in Karbabad CM20 (Capital Governorate).

This base station sited in the middle of Karbabad village, which is located in the Capital Governorate. The measurement was conducted on the roof of 3 stories building which locates at distance 118 m from the base station. The address of this building is: House: 63, Karbabad Avenue, Block: 432. This base station is operated by Batelco. The frequency band for measurements was GSM900.

The highest level of RF radiation was recorded at 05:54 a.m. which was -19.62 dBm (about 516 $\mu W/m^2$) and the lowest level of RF radiation was recorded at 03:48 p.m. which was -21.52 dBm (about 315 $\mu W/m^2$). The average level of RF radiation -20.1738 (about 394 $\mu W/m^2$)

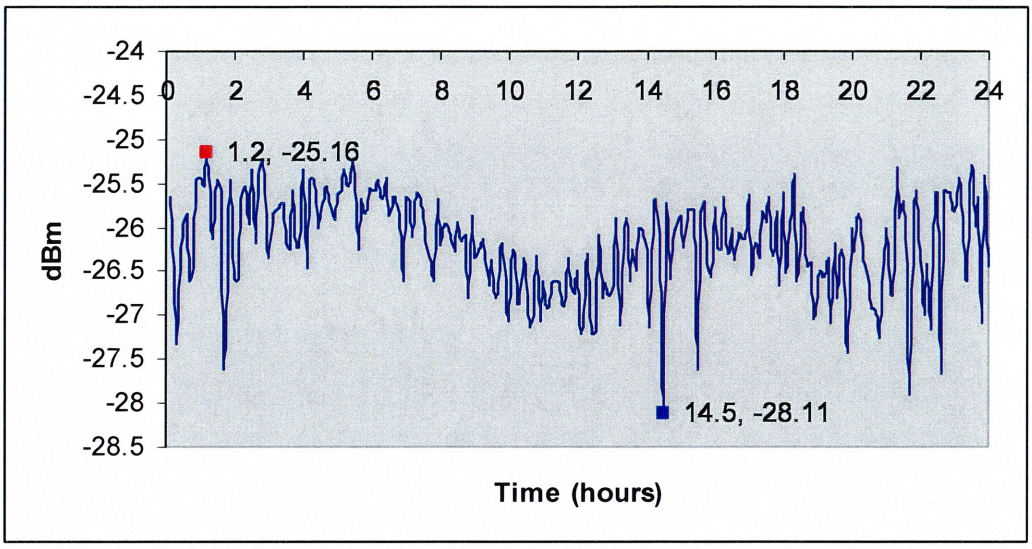


Figure 5.19: Long term measurements of RF emission from the base station in Samaheej (Al Muharraq Governorate).

This base station sited in the Samaheej, one village of Al Muharraq Governorate. The measurement was conducted on the rooftop of two stories building which locates at distance 192 m from the base station. House: 735, Road: 3326, Block: 233 This base station is operated by MTC.

The highest level of RF radiation was recorded at 01:12 a.m. which was -25.16 dBm (about 124 $\mu W/m^2$) and the lowest level of RF radiation was recorded at 02:30 p.m. which was -28.11 dBm (about 69.59 $\mu W/m^2$). The average level of RF radiation -26.1928 (about 98 $\mu W/m^2$)

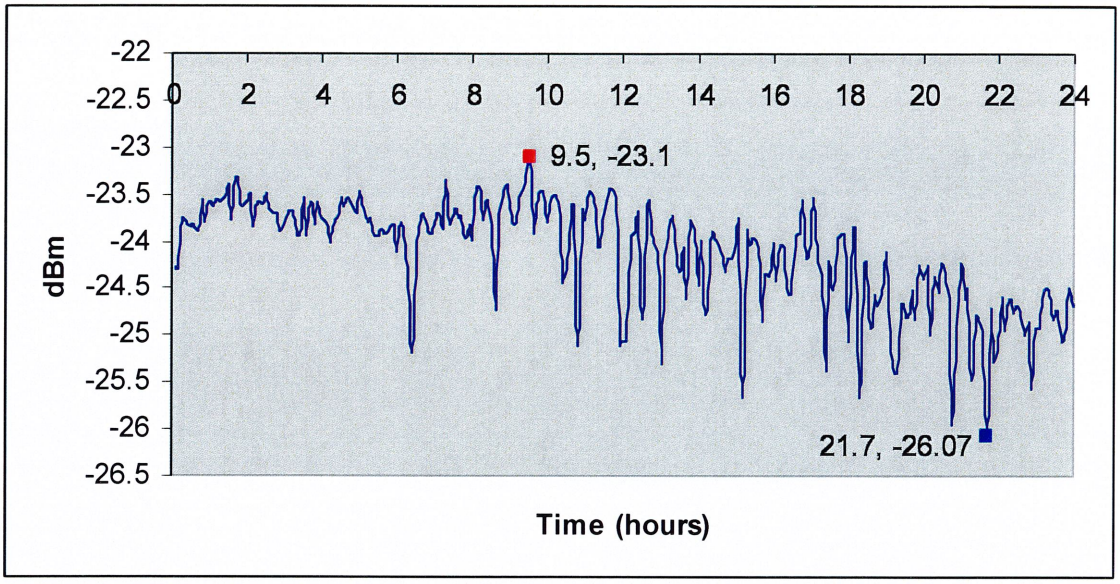


Figure 5.20: Long term measurements of RF emission from the base station in Maqabah N5 (Northern Governorate)

This base station sited in the middle of Maqabah village, in the Northern Governorate. The measurement was conducted on the roof of 3 stories building which locates at distance 147 m from the base station. This base station is operated by Batelco.

The highest level of RF radiation was recorded at 09:30 a.m. which was -23.10 dBm (about 182 $\mu W/m^2$) and the lowest level of RF radiation was recorded at 09:42 p.m. which was -26.07 dBm (about 98 $\mu W/m^2$) .The average level of RF radiation -24.1292 (about 162 $\mu W/m^2$)

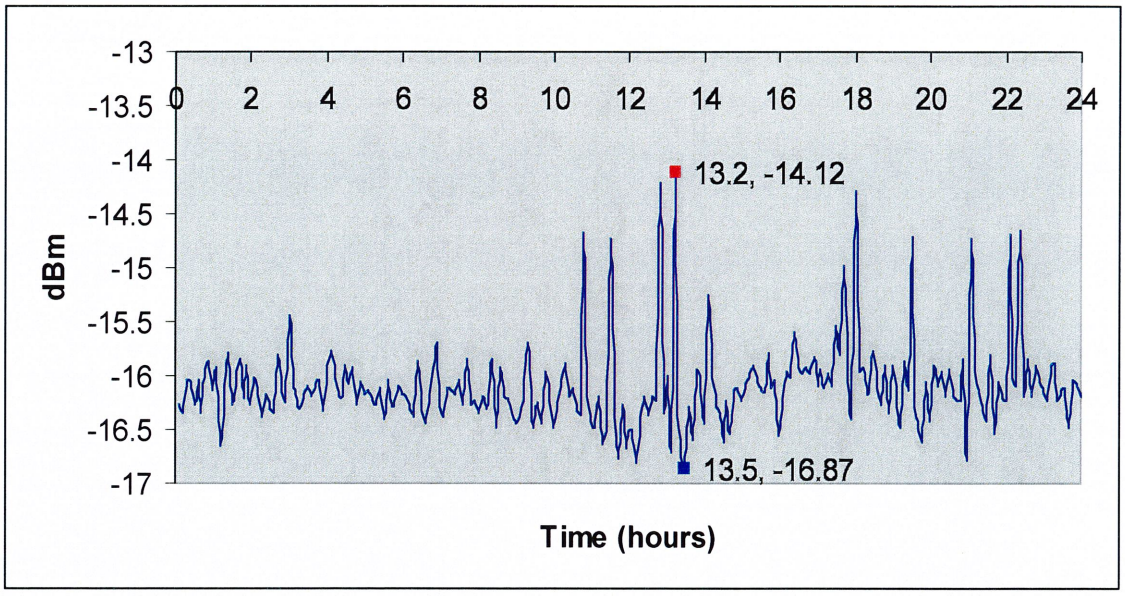


Figure 5.21: Long term measurements of RF emission from the base station in Ras Al Rumman CM22 (Capital Governorate)

This base station sited at Ras Al-Rumman, at the City Center of the Capital Governorate. The measurement was conducted on the roof of 3 stories building which locates at distance 50 m from the base station. The address of this building is: Building: 45, Road: 601, Block: 306. This base station is operated by Batelco.

The highest level of RF radiation was recorded at 01:12 a.m. which was -14.12 dBm (about 1680 $\mu W/m^2$) and the lowest level of RF radiation was recorded at 01:30 p.m. which was -16.87 dBm (about 802 $\mu W/m^2$) .The average level of RF radiation -16.095 (about 978 $\mu W/m^2$)

5.3 Street Mapping of Power Density:

Additional measurements but necessarily of limited nature were made in the vicinity of the base station to determine the RF Radiation distribution in the streets around the base station. The street mapping of RF radiation levels was conducted in one base station. This base station locates at Karbabad village (number CM20 on Figure 5.2) in the Capital Governorate (see appendix 3 for the streets numbers map). Twenty locations around the base station within 550 m were specified. For each location, the power density for the GSM900 band was measured because the RF radiation of the other two bands, GSM1800 and UMTS, are much less than GSM900 band. The results were presented as a map (see Figure 5.22).

The result showed two main conclusions. First, as was stated in theory, the maximum power density was at distance about 180 m from the base station where the mean beam expected to reach the ground. Second, where the beam of antenna was shielded by the buildings, the power density was very low (10 $\mu W/m^2$ or less).



Figure 5.22: Street mapping of RF power density around base station in Kababad.

CHAPTER 6

6. Conclusion

Mobile phones and their base stations have been become one of fastest widespread technology worldwide. However, there are increasing concerns about the possible biological and health effects from the radiofrequency (RF) radiation from these base stations. Many studies have been conducted to study the effects of this radiation on cells, animals and human. Various organizations and authorities reviewed these studies and based on these reviews and the currently available scientific data, they set a guidelines or limits to protect both workers and the general public from potential adverse health effects. Some of these organizations and authorities are International Commission of Non-Ionizing Radiation Protection (ICNIRP), the Institute of Electrical and Electronics Engineers (IEEE), the National Radiological Protection Board (NRPB) in the UK, the Federal Communications Commission (FCC) in the USA, the Australian Radiation Protection and Nuclear Safety Agency (ARPANSA), Health Canada (HC) and Italy.

In this study, both the ICNIRP limit and the national limit proposed by the Pollution Control Section of the Public Commission for the Protection of Marine Resources, Environment and Wildlife in Bahrain (PCPMREW) were used in our analysis and discussion of the results. This because ICNIRP limit is one of the most limit recommended by many countries and organization.

The main aim of this thesis was to measure the RF radiation levels from mobile phone base stations in the Kingdom of Bahrain. Three types of measurements were conducted, the environmental measurements, long term measurements and street mapping of power density of the RF radiation.

The first type of measurements, environmental measurements, is the main type of measurements. It considers the RF radiation levels from the base stations operated by the two operators in the Kingdom of Bahrain, Batelco and MTC, for the three bands: GSM900 which is operated in the frequency range between 925 and 960 MHz, GSM1800 which is operated in

the frequency range between 1805 and 1880 MHz, and UMTS, which is operated in the frequency range between 2110 and 2170 MHz. We had taken relatively large sample size 70 out of 280 (25 % of the total against the accepted known sampling size - which is 15%). We had covered all the governorates in Bahrain (5 Governorates). This means covering nearly 50 towns in the Kingdom of Bahrain.

The results of this type of measurements showed that the RF radiation was much less than exposure limits issued by ICNIRP limit or by national PCPMREW limit. The RF radiation levels in the band of GSM900 found to be the dominant and so the conclusions on the few paragraphs below mention this band. Among all mobile phone base stations under survey (70 base stations), the highest RF radiation level was found at Sanabis, one town of the Capital governorate, which was 3400 $\mu W/m^2$ in terms of power density. This value is about 0.073% of ICNIRP limit (which is about 4.63 W/m^2) (1362 times less) and 3.400% of PCPMREW limit (which is 0.1 W/m^2) (29 times less). In terms of Electric Field Strength (**E**) and Magnetic Field Strength (**H**) it was 1.133 V/m and 3.007 mA/m respectively. These values represent about 2.7% of ICNIRP limit. This Governorate, Capital, also has the highest average of power density among the other Governorates which was 883.93 $\mu W/m^2$. This average value is about 0.019% of ICNIRP limit (5204 times less) and 0.884% of PCPMREW limit (113 times less).

This high power density value (3400 $\mu W/m^2$) is almost 4 times greater than the average value (883.93 $\mu W/m^2$) for the Capital governorate or almost 6 times greater than the overall average (577.64 $\mu W/m^2$) for the five governorates in the band of GSM900. The lowest value of power density (104.40 $\mu W/m^2$) in the Capital governorate is almost 33 times less than this highest value. This shows that there are large variations of RF radiations levels between highest and lowest values of power density. However, these recorded values represent only less than 0.1% of ICNIRP limit. This high power density in Sanabis was anlysed and attributed to many factors, i.e. due to larger output power of the base station that emitted from the antenna and due to larger capacity base stations having multiple transmitters where output power can vary over time and with the number of calls being handled.

For the other Governorate, Al Muharraq Governorate had an average power density of 697.19 $\mu W/m^2$. This average value is about 0.015% of ICNIRP limit (6641 times less) and 0.697% of PCPMREW limit (143 times less). The highest level of RF radiation in term of power density

was found in Al Hidd (site no.1). The frequency of RF radiation was 957 MHz and its power density was 1800 $\mu W/m^2$. However, this value is about 0.039% of ICNIRP limit (2572 times less) and about 1.800% of PCPMREW limit (56 times less). This base station is operated by MTC.

For the Northern Governorate, the average power density was 471.37 $\mu W/m^2$. This average value is about 0.010% of ICNIRP limit (9822 times less) and 0.471% of PCPMREW limit (212 times less). The highest power density was found in Hamad Town (roundabout 1). The frequency of RF radiation was 948 MHz and its power density was 985.63 $\mu W/m^2$. However, this value is about 0.021% of ICNIRP limit (4697 times less) and is about 0.986% of PCPMREW limit (101 times less). This base station is operated by Batelco.
For Central Governorate, the average was 384.10 $\mu W/m^2$. This average value is about 0.0083% of ICNIRP limit (12054 times less) and 0.384% of PCPMREW limit (260 times less). The highest power density was found in Salmabad Town. The frequency of RF radiation was 942 MHz and its power density was 760.48 $\mu W/m^2$. However, this value is about 0.016% of ICNIRP limit (6088 times less) and is about 0.760% of PCPMREW limit (131 times less). This base station is operated by Batelco.

For Southern Governorate, the average was 451.59 $\mu W/m^2$. This average value is about 0.0098% of ICNIRP limit (10253 times less) and is about 0.452% of PCPMREW limit (221 times less). The highest power density was found in Al Zalaq. The frequency of RF radiation was 959 MHz and its power density was 1530 $\mu W/m^2$. However, this value is about 0.033% of ICNIRP limit (3026 times less) and is about 1.530% of PCPMREW limit (65 times less).

The average power density for all base station under survey at the five governorates for the band of GSM900 was 577.64 $\mu W/m^2$ which is 0.012% of ICNIRP limit (8015 times less) and 0.578% of PCPMREW limit (173 times less).

For the GSM1800 band, the highest level of power density was recorded at Sanabis, Capital governorate, which was 1440 $\mu W/m^2$ ($\mathbf{E}$ = 0.737 V/m and $\mathbf{H}$ = 1.958 mA/m). This value is about 0.016% of ICNIRP limit and 1.440% and of PCPMREW limit. The overall average of the power density for the five governorates for this band was 70.24 $\mu W/m^2$ which represents about 0.00078% of ICNIRP limit and about 0.070% of PCPMREW limit.

For the UMTS band, the highest level of power density was recorded at Ras Al Rumman (site 2), Capital governorate, which was 647.39 $\mu W/m^2$ (**E** = 0.494 V/m and **H** = 1.311 mA/m). This value is about 0.0065% of ICNIRP limit, and 0.647% of PCPMREW limit. The overall average of the power density for the five governorates for this band was 44.04 $\mu W/m^2$ which represents about 0.00044% of ICNIRP limit and about 0.044% of PCPMREW limit.

When comparison our results with previous studies results we can see some similarity with some studies and some differences with the others. The highest level of RF radiation recorded in our study was 3400 $\mu W/m^2$ (**E**=1.133 V/m and **H**=3.007 mA/m) which is almost same result for Kuwait (**E** is between 0.05 and 1.13 V/m) and almost same as PCPMREW results, which varies from 2 to 4000 $\mu w/m^2$.
In Australia, the result was lower (1780 $\mu W/m^2$). It is also lower in Malaysia according to the study of Malaysian Institute for Nuclear Technology Research (MINT).The averaged radiation levels produced by the mobile phone base stations were found to vary between 8×10^{-5} V/m (0.000017 $\mu W/m^2$) and 7.05×10^{-2} V/m (13.18 $\mu W/m^2$),

The second type of measurements was to investigate how RF radiation varies during long term duration. The long term measurements, 24 hours duration, was conducted for 5 base stations for the band of GSM900. These base stations are at Maqabah (Northern Governorate), Jidhafs (Northern Governorate), Ras Al Rumman (Capital Governorate), Karbabad (Capital Governorate) and Samaheej (Al Muharraq Governorate). This type of measurement gave us an idea about the variation of RF radiation from mobile phone base stations during a day. The results showed that there is a variation of RF radiation during the day which can be described as random and unpredictable. Moreover, the results showed the maximum and minimum of RF radiation during the 24 hours and therefore how far between them. This can help us to know also how the result in type one of measurements, environmental measurements, could change when the measurement conducted at another time of the day. Furthermore, this type gives us information about the level of RF radiation on rooftop of buildings around the base stations. The nearest distance to the base station was 50m with power density of 1680 $\mu W/m^2$ compared to the highest RF radiation level found on the ground 572.06 $\mu W/m^2$ at distance 78 m for the same base station.

The street mapping of RF radiation levels around a base station, the third types of measurements, was conducted. One base station was chosen. This base station locates in

Capital Governorate at Karbabad village (number CM20 on Figure 5.2). Twenty locations around the base station within 550 m were specified. For each location, the power density for the GSM900 band was measured. From the results, one can conclude two main conclusions. First, as we stated in theory, the highest power density was at distance about 180 m from the base station where the mean beam expected to reach the ground. Second, where the beam of antenna was shielded by the buildings, the power density was very low (less than 10 $\mu W/m^2$). In conclusion, the RF radiation levels were very low in the street, which indicates that this radiation was shielded and dissipated. This led to a conclusion that in every location that was measured in type one, the level in the area surrounding the base station expected to be much less than our results because of the shielding of buildings and trees.

In conclusion, we found that the measured RF radiation levels from the mobile phone base stations in the Kingdom of Bahrain are much lower than the exposure limits set by ICNIRP and PCPMREW.

We recommend the following:

- Although the levels of RF radiation from base stations in the Kingdom of Bahrain at ground level is much less than exposure limits, but we recommend the monitoring and assessment of the RF radiation levels of mobile phone base stations should be continue. This procedure is to ensure that RF radiation levels do not exceed the exposure limit, especially that there is continuous installing of base stations through out the Kingdom due to increasing in the demand of mobile phone technology.

- More attention and further studies should be conducted to study the levels of RF radiation from mobile phones base stations at the levels above the ground level in the building surrounding the base station. We expected that the level of RF radiation could be higher than our results. Quick measurements was conducted for one base station at Ras Al Rumman in the Capital Governorate showed that the level of RF radiation at the vertical distance equal to 12m exceeded the highest levels obtained fro ground level measurements (see appendix 4).

- More should be taken in considerations for the near field measurements and health effects.

- There are now many mobile phone base stations from both operators (Baletco and MTC) are installed very close to each other –at which the distance between them is less than 500 m. This may lead to enhancement of exposure to RF radiation. We recommended that future base stations should be installed within an about 500 m or more from other base stations. This because if there are more than one base stations within this range of distance, the level of RF radiation expected to be double in the area between these base stations due to their radiation. However, in current level of RF radiation, according to this study, this situation not expected to exceed the exposure limit.

- A national database should be set up by Telecommunications Regulatory Authority (TRA) in cooperation with the two mobile phone network operator, Batelco and MTC, giving information about all base stations in the Kingdom of Bahrain. For each, this should list: the name of the mobile phone network operating company; the height of the antenna above ground level; the date that transmission started; the frequency range and signal characteristics of transmission; the transmitter power; and the maximum power output under the Wireless Telegraphy Act. Moreover, this information should be readily accessible by the public, and held in such a form that it would be easy to identify, for example, all base stations within a defined geographical area, and all belonging to a specified operator. Such transparency is useful to public, environmentalists and researchers.

- We recommend that distinctive attention should be given to the base stations near to schools, health centers and other sensitive sites. We notice that in many cases the base station are close to one or more schools or close to a kindergarten (see photos 1, 5, 7, 20, 27, 30, 32, 47, 52 and 55 in appendix 1). These base stations should be checked regularly and be confident of not even approach to the exposure limits because some studies suggested that children are more sensitive to RF radiation.

- Researchers should stick with ICNIRP limits, as it is approved by World heath Organisation and by the group of expert. Other groups had put limits much lower than ICNIRP. For example the limits by Germany detector's manufacturing, AARONIA AG, had put the limits to 5 $\mu W/m^2$ for GSM900 band which is 900000 times the ICNIRP limit. Another example is the limit recommended by Bund für Umwelt und

Naturschutz Deutschland (BUND: League for the environment and nature conservation, Germany) in 1997 which is 0.00045 W/m^2 for GSM900 (Aaronia AG, 2007). This value is 10000 times the ICNIRP limit. This will make the recorded power density in Bahrain are at dangerous level according to their standards.

The sustainable development is defined as balancing the fulfillment of human development needs with the protection of the natural environment so that these needs can be met not only in the present, but in the indefinite future. Therefore, one can conclude that the mobile communication system in Bahrain supports sustainable development. This is because it is widely used over the whole resident and commercial areas, which provides efficient communication, and hence, social and economic benefits without environmental damage or hazards. This work reveals that the level of RF radiation flux in all of the surveyed mobile's phone base station is relatively very low, i.e. do not exceed even 2 % of the set international limit.

References

Aaronia AG, 2007. *"Exposure limits and unit conversions"*. Available at: http://test1.contenttest.net/grenzwerte_d_en.shtml#14

Abdel-Rassoul G., Abou El-Fateh O., Abou Salem M., Michael A., Farahat F., El-Batanouny M. and Salem E., (2006) *"Neurobehavioral effects among inhabitants around mobile phone base stations"*, *NeuroToxicology*, doi:10.1016/j.neuro.2006.07.012

Ali, M. Y. M.; Abd Rahim, R.; Abd Majid, M. A. and Nizam, M. A. (2003). *"Radiofrequency and Microwave Radiation Safety Assessment of Mobile Telephone Base Stations in Malaysia"*. Non-Ionising Group, Special project,Malaysian Institute for Nuclear Technology Research (MINT)Bangi, 43000 Kajang, Selangor. Proceedings of the International Conference on Non-Ionizing Radiation at UNITEN (ICNIR 2003), Electromagnetic Fields and Our Health 20th – 22nd October 2003

Al-Otaibi, A. H.; Al-Ajmi, D.; Williams, T.; McGee, D.; Dennis, J. A. and Beg M. U. (1998). *"Monitoring of Electromagnetic Radiation from Cellular Base Stations in Kuwait"*. Radiation Protection Dosimetry 80:397-404

ARPANSA: Australian Radiation Protection and Nuclear Safety Agency (2002). *"Maximum Exposure Levels to Radiofrequency Fields —3 kHz to 300 GHz"*. Radiation Protection Series Publication No. 3, This Standard was approved by the Radiation Health Committee on 20 March 2002.

ARPANSA: Australian Radiation Protection and Nuclear Safety Agency (2000). *"Levels of Radiofrequency Radiation from GSM Mobile Telephone Base Stations"*. Technical Report 129, JANUARY 2000. Lower Plenty Road YALLAMBIE VIC 3085.

Batelco: Bahrain Telecommunication Company. (2006). *"About Batelco, History and Milestones"*. Kingdom of Bahrain. available at: http://www.batelco.com/history.asp
Classic K. (2007). *"Radiofrequency (RF) Radiation (Includes RF from broadcast antennas, portable radio systems, microwave antennas, satellite, and radar)"*. Health Physics Society. Available at: http://hps.org/hpspublications/articles/rfradiation.html

Cleveland, R. F. and Ulcek, J. L. (1999), *"Questions and Answers about Biological Effects and Potential Hazards of Radiofrequency Electromagnetic Fields"*. Federal Communications Commission (FCC), Office of Engineering & Technology, OET BULLETIN 56. Fourth Edition. Washington. D.C.

Cleveland, R. F.; Sylvar, D. M. and Ulcek, J. L. (1997). *"Evaluating Compliance with FCC Guidelines for Human Exposure to Radiofrequency Electromagnetic Fields"*. Standards Development Branch Allocations and Standards Division, Office of Engineering and Technology, Federal Communications Commission. Washington, D.C. 20554. OET BULLETIN 65. Edition 97-01.

CSTEE: Scientific Committee on Toxicity, Ecotoxicity and the Environment. (2001). *"Opinion on Possible effects of Electromagnetic Fields (EMF), Radio Frequency Fields (RF) and Microwave Radiation on human health"*. EUROPEAN COMMISSION, DIRECTORATE-GENERAL HEALTH AND CONSUMER PROTECTION, Directorate C - Scientific Opinions, Unit C2 - Management of Scientific Committees; scientific co-operation and networks, Expressed at the 27th CSTEE plenary meeting. Brussels, 30 October 2001

Dasenbrock C. (2005). *"Animal carcinogenicity studies on radiofrequency fields related to mobile phones and base stations"*. Fraunhofer Institute of Toxicology and Experimental Medicine (ITEM), Nikolai-Fuchs-Str. 1, 30625 Hannover, Germany, Toxicology and Applied Pharmacology 207 (2005) S342 – S346

FCC: Federal Communications Commission (2006). "Human Exposure To Radio Frequency Fields: Guidelines For Cellular & PCS Sites". Available at: http://www.fcc.gov/cgb/consumerfacts/rfexposure.html

FCC: Federal Communications Commission and LSGAC: Local and State Government Advisory Committee (2000). *"A Local Government Official's Guide to Transmitting Antenna RF Emission Safety: Rules, Procedures, and Practical Guidance"*. June 2, 2000

Fuller K., Gulson A. D., Judd P. M., Lowe A. J. and Shaw J. (2002). *"Radiofrequency Electromagnetic Fields in the Cookridge Area Leeds"*. NRPB, Chilton, Didoot, Oxon OX11 0RQ. UK.

Health Canada (1999). *"Limits of Human Exposure to Radiofrequency Electromagnetic Fields in the Frequency Range from 3 kHz to 300 GHz, SafetyCode 6"*. Environmental Health Directorate, Health Protection Branch, Published by authority of the Minister of Health. Minister of PublicWorks and Government Services, Canada 1999.

Health Council of the Netherlands. (2000). *GSM base stations"*. The Hague: Health Council of the Netherlands. publication no. 2000/16E.

Health Council of the Netherlands. (2002). *"Mobile telephones, an evaluation of health effects"*. The Hague: Health Council of the Netherlands; publication no. 2002/01E.
HPA: Health Protection Agency (2006), "Mobile Telephony and Health". UK. Available at: http://www.hpa.org.uk/radiation/understand/information_sheets/mobile_telephony/base_stations.htm

ICNIRP: International Commission on Non-Ionizing Radiation Protection. (1998). *"Guidelines for limiting exposure to time-varying electric, magnetic and electromagnetic fields (up to 300 GHz)"*. Health Phys, 74(4), 494522.

ICNIRP: International Commission on Non-Ionizing Radiation Protection (1999). *"Use of the ICNIRP EMF guidelines"*. March 31, 1999. Available at: http://www.icnirp.de/documents/Use.htm

IEEE: Institute of Electrical and Electronics Engineers. (1992). *"standard for safety levels with respect to human exposure to radiofrequency electromagnetic fields, 3 KHz to 300 GHz"*. New York, 1EEE C95.1-1991, 1992.

IEGMP: Independent Expert Group on Mobile Phones. (Chairman: Stewart W.). (2000). *"Mobile Phones and Health"*. National Radiological Protection Board, Chilton, Didcot, Oxon OX11 0RQ, UK.

Keetley V., Wood A. W., Spong J., Stough C. (2006). *"Neuropsychological sequelae of digital mobile phone exposure in humans"* Neuropsychologia 44 (2006) 1843–1848.

Levallois, P.; Guvin, D.; Lajoie, P. and Saint-Laurent Josee. (1997). *"Review of exposure guidelines for electromagnetic fields (0-300GHz)"*, Institute de recherché en sante et en securite du travail [Occupational Health and Safety Research Institute (Quebec)].

Mann K., Roschke J., (2004). *"Sleep under exposure to high-frequency electromagnetic fields"*. Department of Psychiatry, University of Mainz, Untere Zahlbacher Str. 8, D-55101 Mainz, Germany. Sleep Medicine Reviews (2004) 8, 95–107.

Mann, S. M.; Cooper, T. G.; Allen, S.G.; Blackwell, R.P. and Lowe, A.J. (2000), *"Exposure to Radio Waves near Mobile Phone Base Stations"*. National Radiological Protection Board. Chilton, Didcot, Oxon OX11 0RQ, UK.

Means, D. L. and Chan, K. W. (2001). *"Evaluating Compliance with FCC Guidelines for Human Exposure to Radiofrequency Electromagnetic Fields. Additional Information for Evaluating Compliance of Mobile and Portable Devices with FCC Limits for Human Exposure to Radiofrequency Emissions"*. SUPPLEMENT C Edition 01-01 To OET BULLETIN 65 Edition 97-01. Office of Engineering and Technology. Federal Communications Commission. Washington, D.C.

MOA: Mobile Operators Association. (2007). *"Base Stations and Masts"* .MOA. Russell Square House, 10-12 Russell Square, London WC1B 5EE, UK. Available at: http://www.mobilemastinfo.com/information/masts.htm

MTC: Mobile Telecommunication Company (2006). Kingdom of Bahrain. Available at: http://www.mtc-vodafone.com.bh/cgi-bin/MTCIM/webportal/program?BV_SessionID=@@@@@0262768969.1184845530@@@@&BV_EngineID=ccccaddlhlhhikdcflgcegfdffndfkm.0&channelId=-10549&menuChannel=-10561

NRPB: National Radiological Protection Board. (1993). *"Restrictions on human exposure to static and time varying electromagnetic fields and radiation: scientific basis and recommendations for the implementation of the Board's Statement"*. *Doc NRPB*, 4(5), 7.

NRPB: National Radiological Protection Board. (2003). (Chairman: Swerdlow A. J.). *"Health Effects from Radiofrequency Electromagnetic Fields"*. Report of an independent advisory group on non-ionising radiation. Documents of the NRPB. Volume14 No.2 2003. UK.

NRPB: National Radiological Protection Board. (2004). (Chairman: Stewart W.). *"Mobile Phones and Health 2004"*. Documents of the NRPB. Volume15 No.5 2004. UK.

OSHA: Occupational Safety and Health Administration. (1990). *"ELECTROMAGNETIC RADIATION and HOW IT AFFECTS YOUR INSTRUMENTS"*. Electromagnetic Radiation: Field Memo, FIELD SERVICE MEMO. U.S. Department of Labor, OSHA, Cincinnati Laboratory, May 20, 1990, Cincinnati, Ohio. Available at: http://www.osha.gov/SLTC/radiofrequencyradiation/electromagnetic_fieldmemo/electromagnetic.html#Section%206

Preece A. W.; Iwi G.; Davies-Smith A.; Wesnes K.; Butler S. and Varey A. (1999). *"Effect of a 915-MHz simulated mobile phone signal on cognitive function in man"*. International Journal of Radiation Biology, Volume 75, Number 4, 1 April 1999 , pp. 447-456(10). Publisher: Taylor and Francis Ltd.

Rafiqul Islam, Md.; Khalifa, O.; Ali, L.; Azli, A. and Zulkarnain, M. (2006*), "Radiation Measurement from Mobile Base Stations at a University Campus in Malaysia"*. American Journal of Applied Sciences 3 (4): 1781-1784, 2006

Repacholi M. H. (1997). *"Radiofrequency Field Exposure and Cancer: What Do the laboratory Studies Suggest?"*. World Health Organization, Geneva, Switzerland. Environmental Health Perspectives,Vol. 105, Supplement 6 December 1997.

Royal Society of Canada. (1999). *"A Review of the Potential Health Risks of Radiofrequency Fields from Wireless Telecommunication Devices"*. An Expert Panel Report prepared at the request of the Royal Society of Canada for Health Canada. Publication No. RSC. EPR 991, Ottawa, Canada.

Scheaffer R. L., Mendenhall W. and Ott L. (1990). *"Elementary survey sampling"*. EDITION STATEMENT 4th ed. PUBLICATION Boston, Mass.: PWS-Kent Pub., 1990.

Scourias J. (1997). *"Overview of the Global System for Mobile Communications"*. Available at: https://styx.uwaterloo.ca/~jscouria/GSM/gsmreport.html

Swedish radiation protection authority, SSI (Statens strålskyddsinstitut) (2005). *"Recent Research on EMF and Health Risks,Third annual report from SSI's Independent Expert Group on Electromagnetic Fields"*.SSI's Independent Group on Electromagnetic Fields.

Swedish radiation protection authority, SSI (Statens strålskyddsinstitut). (2004). *"Recent Research on Mobile Telephony and Health Risks. Second annual report from SSI's Independent ExpertGroup on Electromagnetic Fields"*. SSI's Independent Group on Electromagnetic Fields.

TRA: Telecommunications Regulatory Authority. (2006). *"Spectrum Policy and Planning"*. A Joint Policy Issued by the Telecommunications Regulatory Authority (TRA) and the Ministry of Transportation (MoT) of the Kingdom of Bahrain. 27 June 2006. Available at: http://www.tra.org.bh/en/pdf/spectrum_policy_TRA_MOT_final.pdf

TRA: Telecommunications Regulatory Authority. (2007). *"Bahrain Telecommunications Sector Customer Data"*. Kingdom of Bahrain. Available at: http://www.tra.org.bh/en/marketCustomer.asp

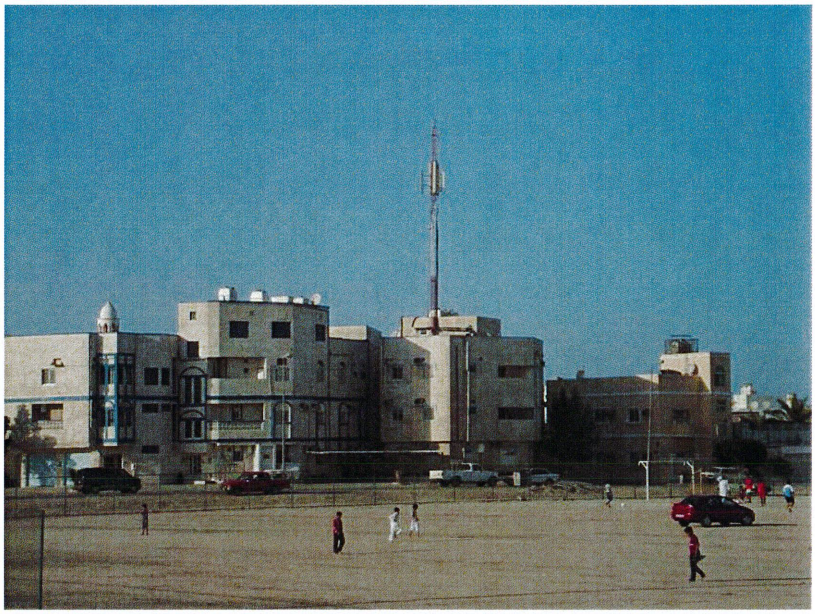
UNEP/WHO/IRPA: United Nations Environment Programme / World Health Organization / International Radiation Protection Association. (1993). *"Electromagnetic fields (300 Hz to 300 GHz"*. Geneva: World Health Organization; Environmental Health Criteria 137; 1993.

Vecchia P., (2007). *"Radiofrequency fields: Bases for exposure limits"*. Available at: http://w3.tue.nl/fileadmin/sbd/Documenten/IRPA_refresher_courses/RF_basesforexposure_limitsRC-6.pdf

Zmirou, D. (2001). *"Mobile telephones, base stations and health. Current state-of-knowledge and recommendations"*. A report to the Director General of Health of France.

Appendixes

Appendix 1: Photos for the mobile phone's base stations is several areas in Bahrain.



1- Al Hidd-1



2- Al Hidd- 2



3- Arad



4- Qalali



5- Qalali-2



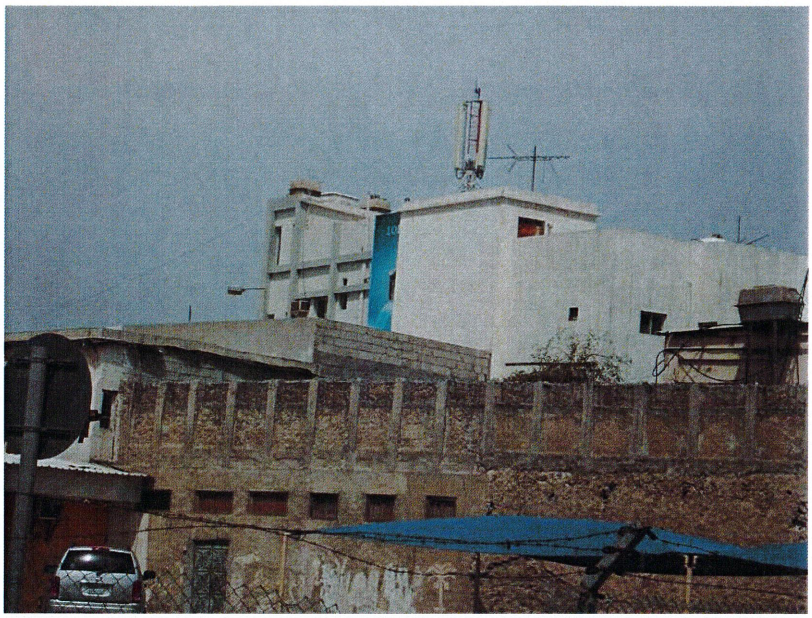
6- Busaiteen



7- Al Hala-2



8- Al Hala-1



9- Souq Al Muharraq



10- Sitra-1



11-Nuwaidrat



12- Sitra- 2



13- Sitra-3



14- Isa Town-1



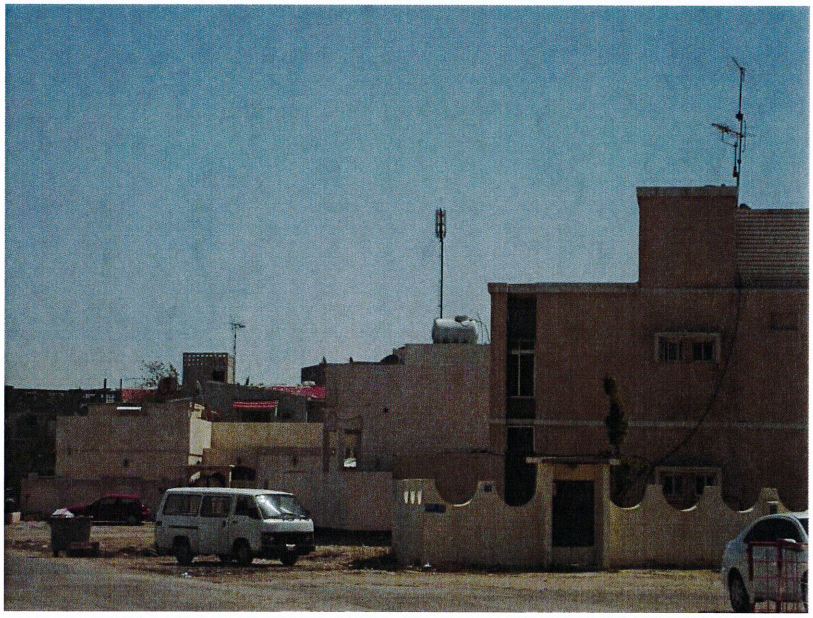
15- Sanad



16- Isa Town-3



17- Salmabad



18- Isa Town-1



19- A’ali-1



20- A’ali-2



21- Bukawara



22- Karbabad



23- Qudaybia



24- Adlia



25- Um Al Hasam



26- Juffair



27- Ras Al Rumman-1



28- Salmania



29- Soqayia-1



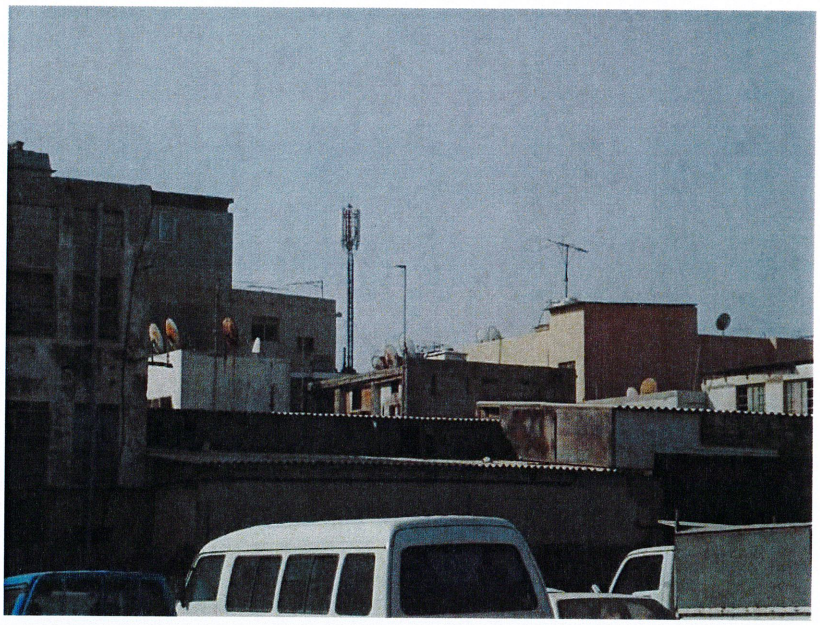
30- Soqayia-2



31- Zinj



32- Al Hoora



33-Noaim



34- Sanabis



35- Magsha



36- Barbar-1



37- Barbar-2



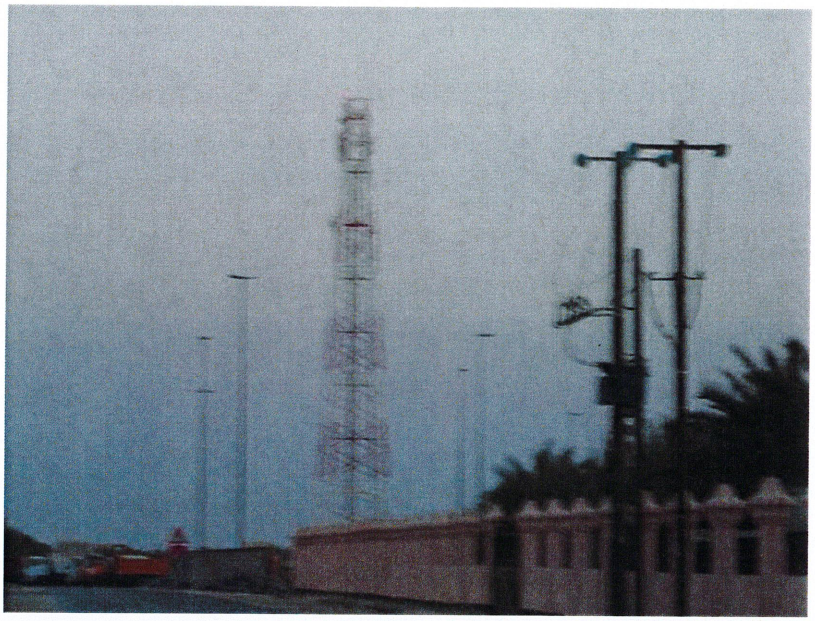
38- Maqabah



39- Jidhafs



40- Budayyi



41- Janabia



42- Buri



43- Dumistan



44- Hamad Town - R. 1



45- Hamad Town – R. 9



46- Hamad Town – R. 17



47- Hamad Town – R. 20



48- W. Riffa-1



49- W. Riffa-2



50- W. Riffa-3



51- Al Zalaq



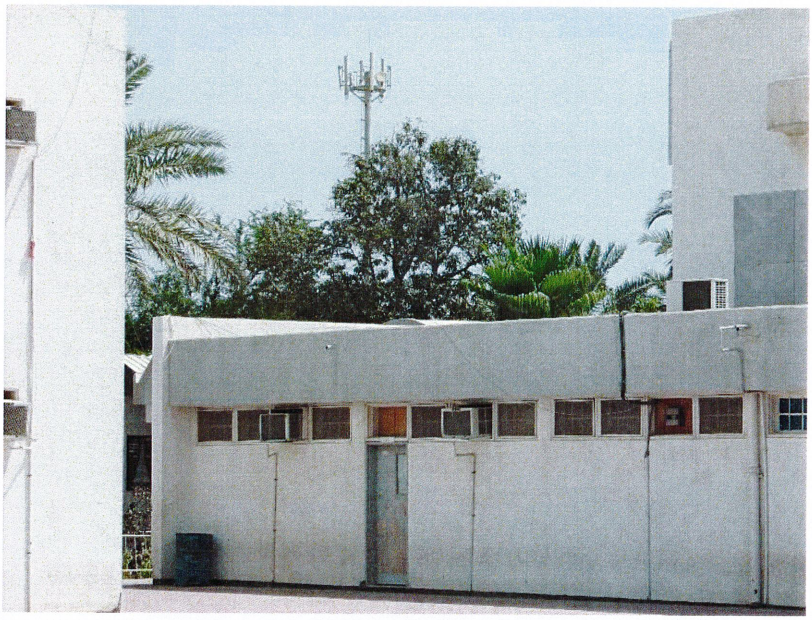
52- Askar



53- Manama

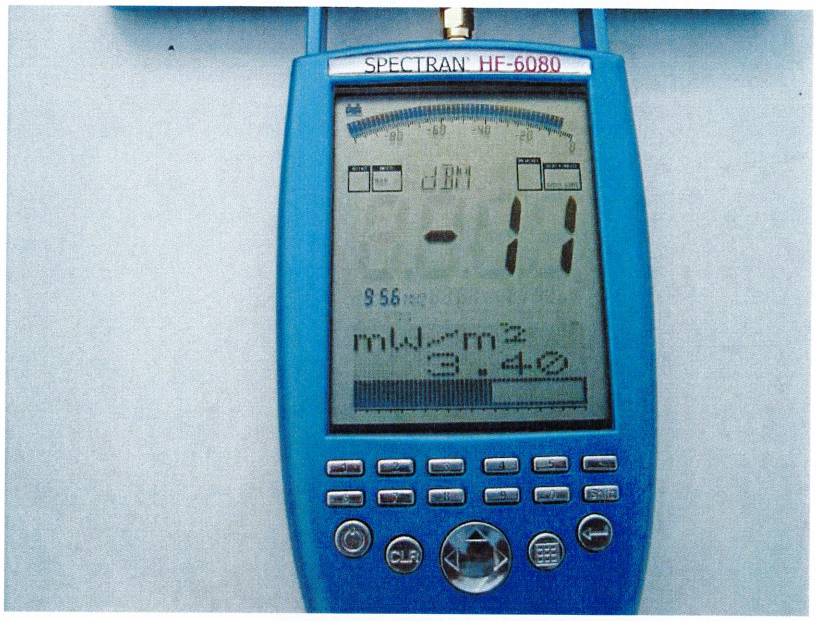


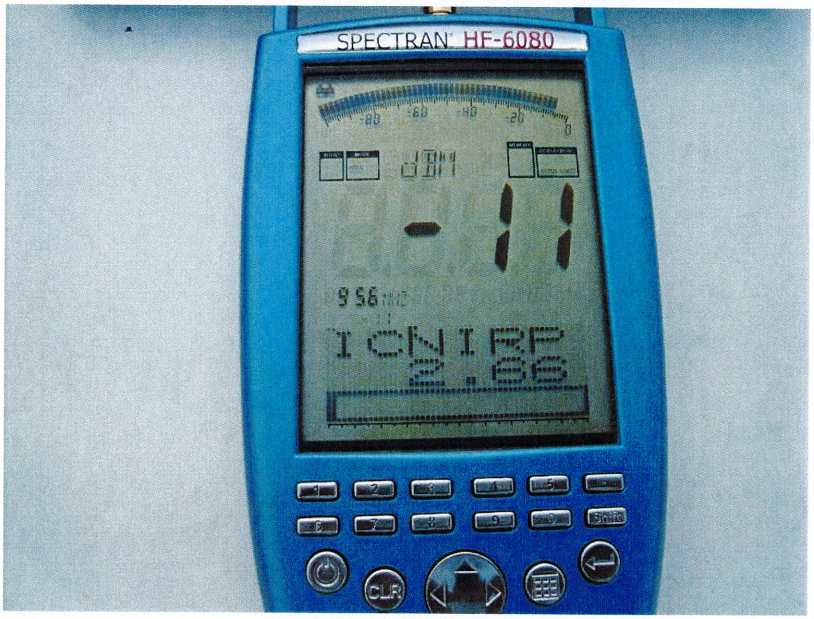
54- Ras Al Rumman-2



55- Al Duraz

Appendix 2: Photos of the display of the measurements using our gauge meter for RF radiation.



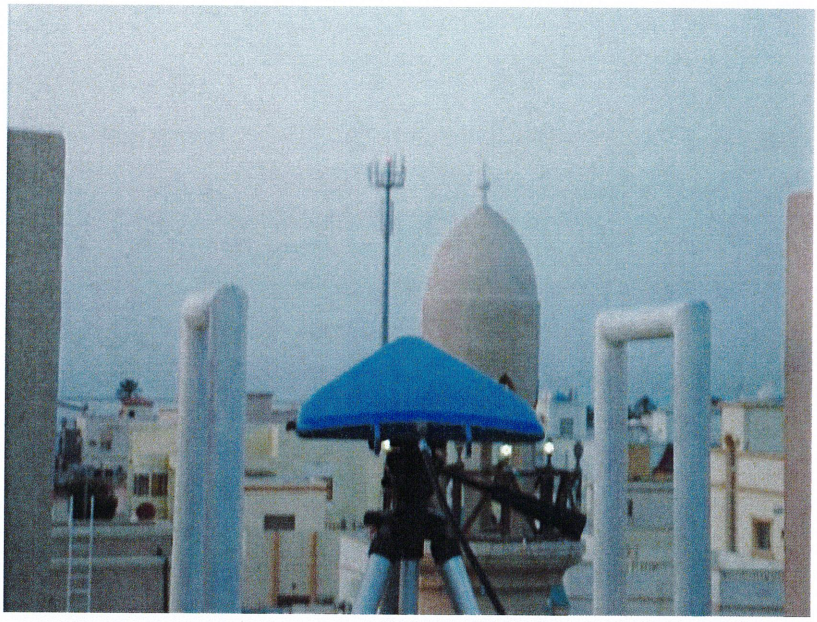


1- Photos of the display of the measurements in Sanabis using our gauge meter for RF radiation.





2- Photos of the display of the measurements in Al Hidd-1 using our gauge meter for RF radiation.

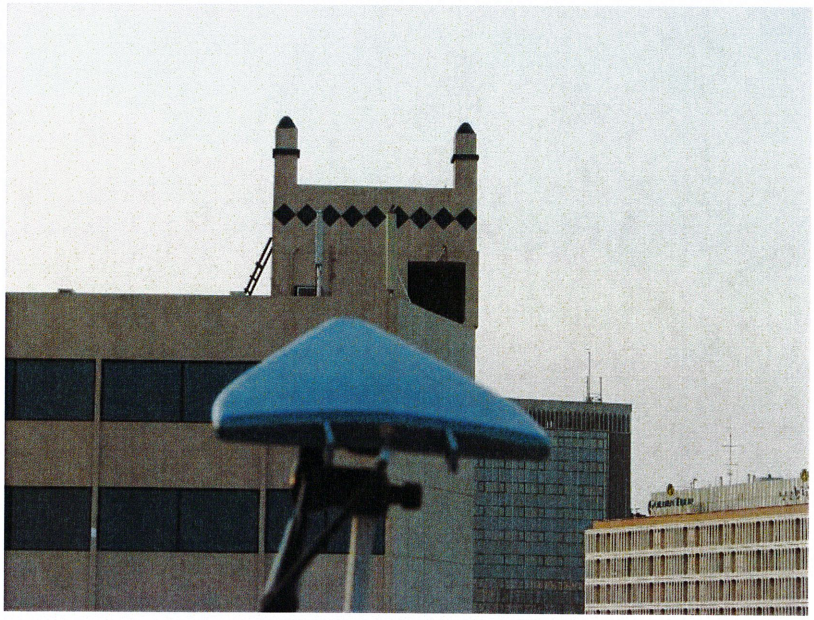




3- Photo shows how we conduct long term measurement in Samaheej (Al Muharraq).

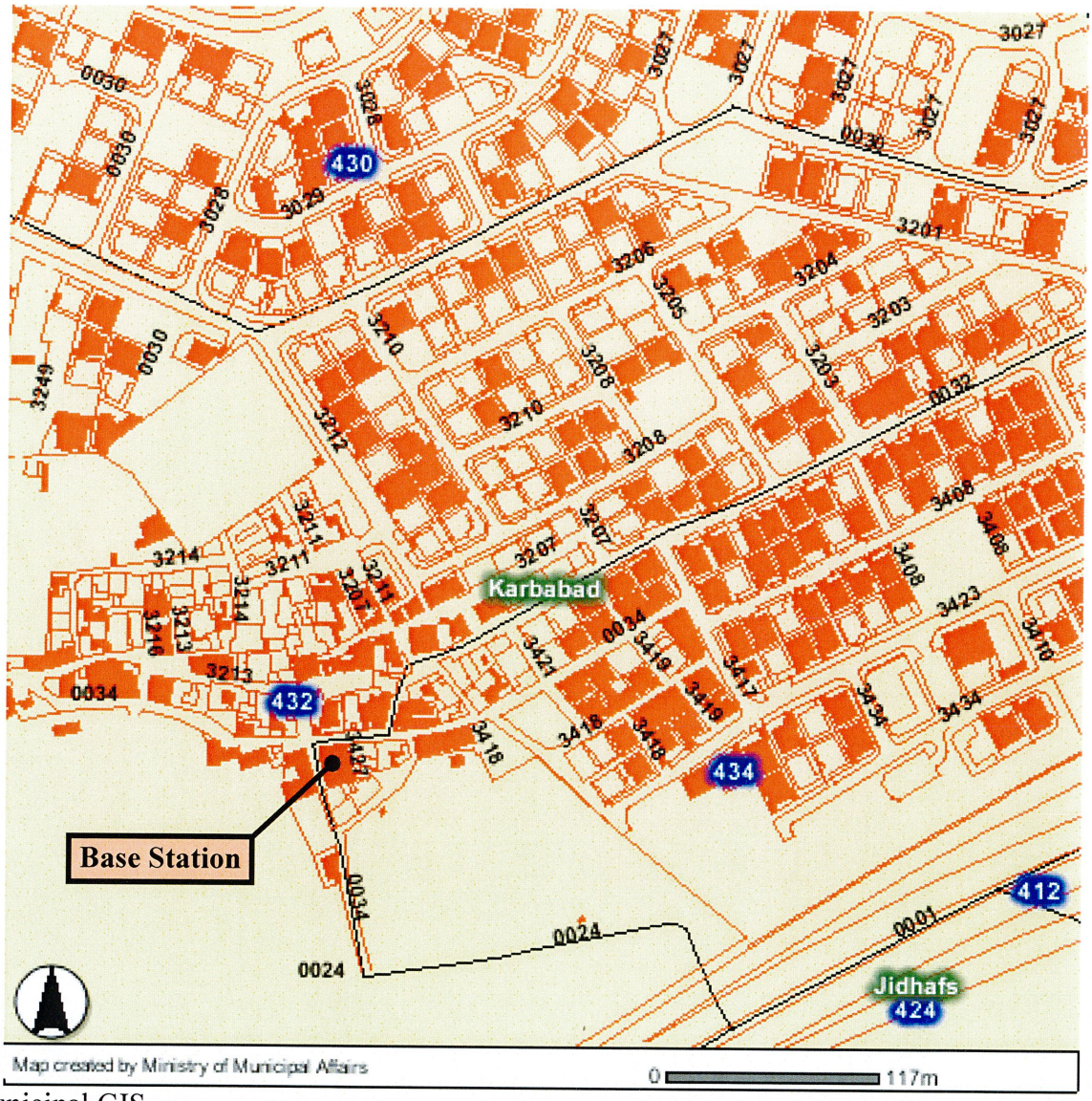


4- Photo shows how we conduct long term measurement in Maqabah (Northern Governorate).



5- Photo shows how we conduct long term measurement in Ras Al Rumman (Capital).

Appendix 3: The street map of Karbabad.



Municipal GIS
Information Systems Directorate
Ministry of Municipalities and Agriculture Affairs

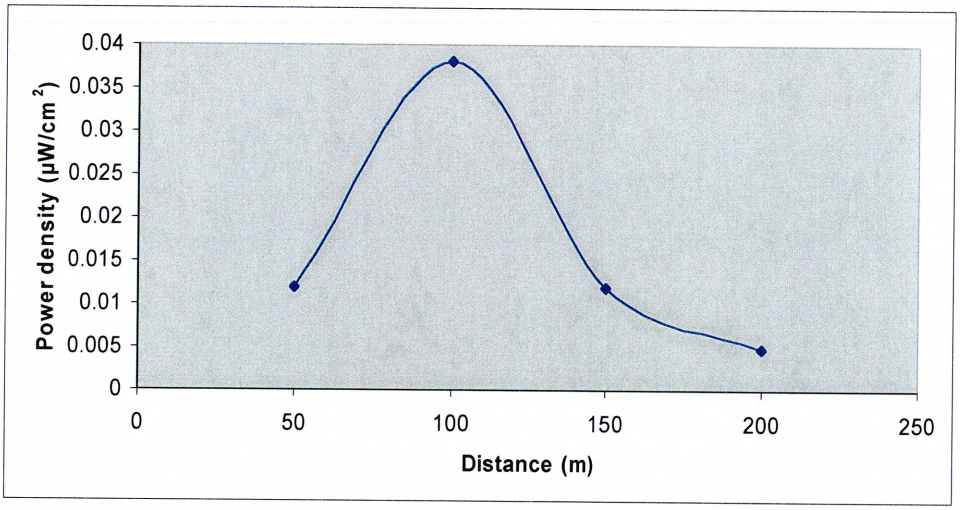
From website:

http://www.ma-investment.gov.bh/website/discover_bah/viewer.htm

Appendix 4: The relation between the power density and the horizontal distance from two different mobile phone's base stations.

The measurements of RF radiation from a mobile phone's base station.

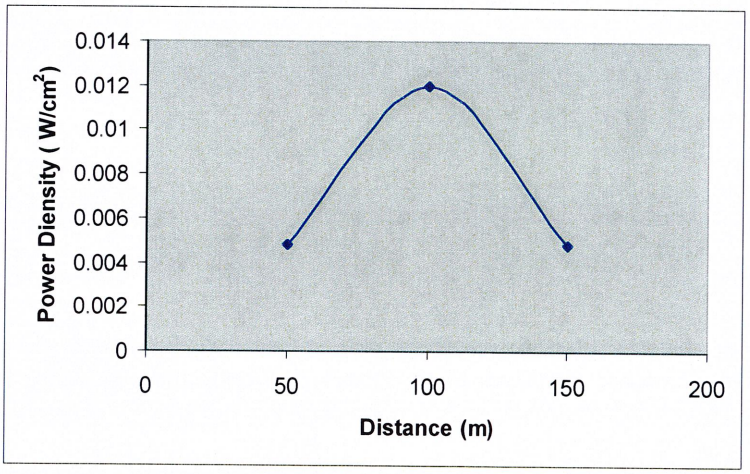
#	Distance (m)	dBm	Power Density (W/m^2)	Power Density ($\mu W/cm^2$)
1	50	-30	0.00012	0.012
2	100	-25	0.00038	0.038
3	150	-30	0.00012	0.012
4	200	-34	0.000048	0.0048



Variation of the power density from a mobile phone's base station with horizontal distance

The measurements to the south of southern base station.

#	Distance (m)	dBm	Power Density (W/m^2)	Power Density ($\mu W/cm^2$)
1	50	-34	0.000048	0.0048
2	100	-30	0.00012	0.012
3	150	-34	0.000048	0.0048



Variation of the power density from a mobile phone's base station with horizontal distance

The highest power density is at 100m from the source.

Appendix 5: Measurement the Levels of Radiofrequency Field (RF) Radiation from a Base Station Installed in the University of Bahrain.

- There are two base stations in the University of Bahrain, one is in the south near the southern gate and the other is in west near the western gate (see Figure 1).

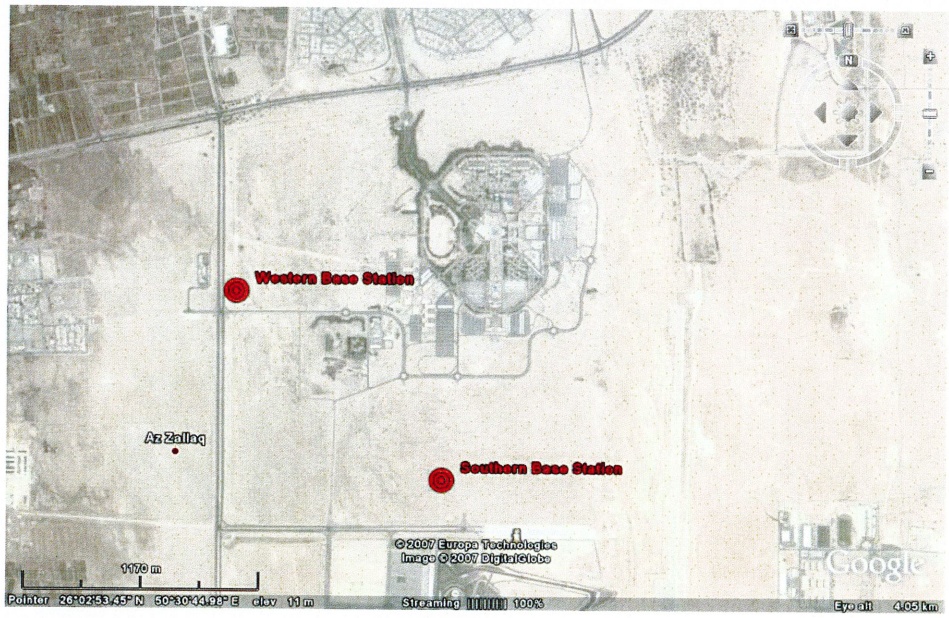


Figure 1: The two base stations in the University of Bahrain.

- For the southern base station we made 8 measurements, 4 in the south direction and 4 in the north direction (see Figure 2).

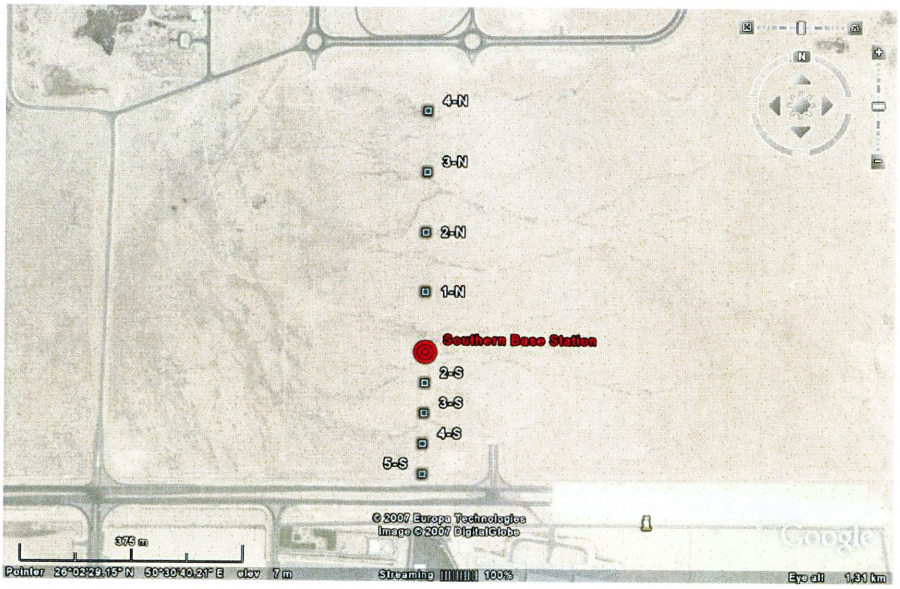


Figure2: The measurements of the power density at different horizontal distances in the southern base station.

The maximum recorded value was 327.5 $\mu W/m^2$ at horizontal distance 300 m to the north which is 0.82% of the ICNIRP exposure limit according to the device and 0.3275% according to PCPMREW exposure limit (see table 1 and 2).

Table 1: The measurements to the south of southern base station.

	Horizontal Distance (m)	dBm	$\mu W/m^2$	$\mu W/cm^2$	% of ICNIRP exposure limit (device)	% of PCPMREW exposure limit
2-S	50	-40	3.73	0.000373	0.08	0.00373
3-S	100	-39	5.56	0.000556	0.1	0.00556
4-S	150	-41	3.24	0.000324	0.08	0.00324
5-S	200	-39	5.30	0.00053	0.1	0.0053

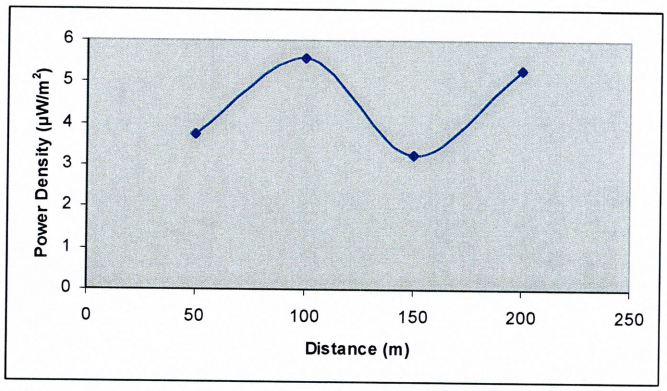


Figure 3: Variation of the power density with horizontal distance at the north of the southern base station at the University of Bahrain.

Table 2: The measurements to the north of southern base station.

	Distance (m)	dBm	$\mu W/m^2$	$\mu W/cm^2$	% of ICNIRP exposure limit (device)	% of PCPMREW exposure limit
1-N	100	-30	37.55	0.003755	0.28	0.03755
2-N	200	-29	49.06	0.004906	0.32	0.04906
3-N	300	-21	327.5	0.03275	0.82	0.3275
4-N	400	-30	41.34	0.004134	0.29	0.04134

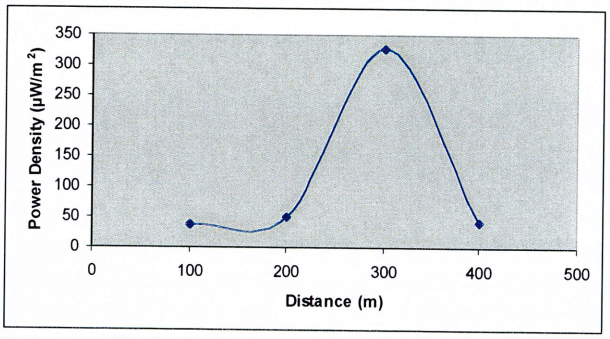
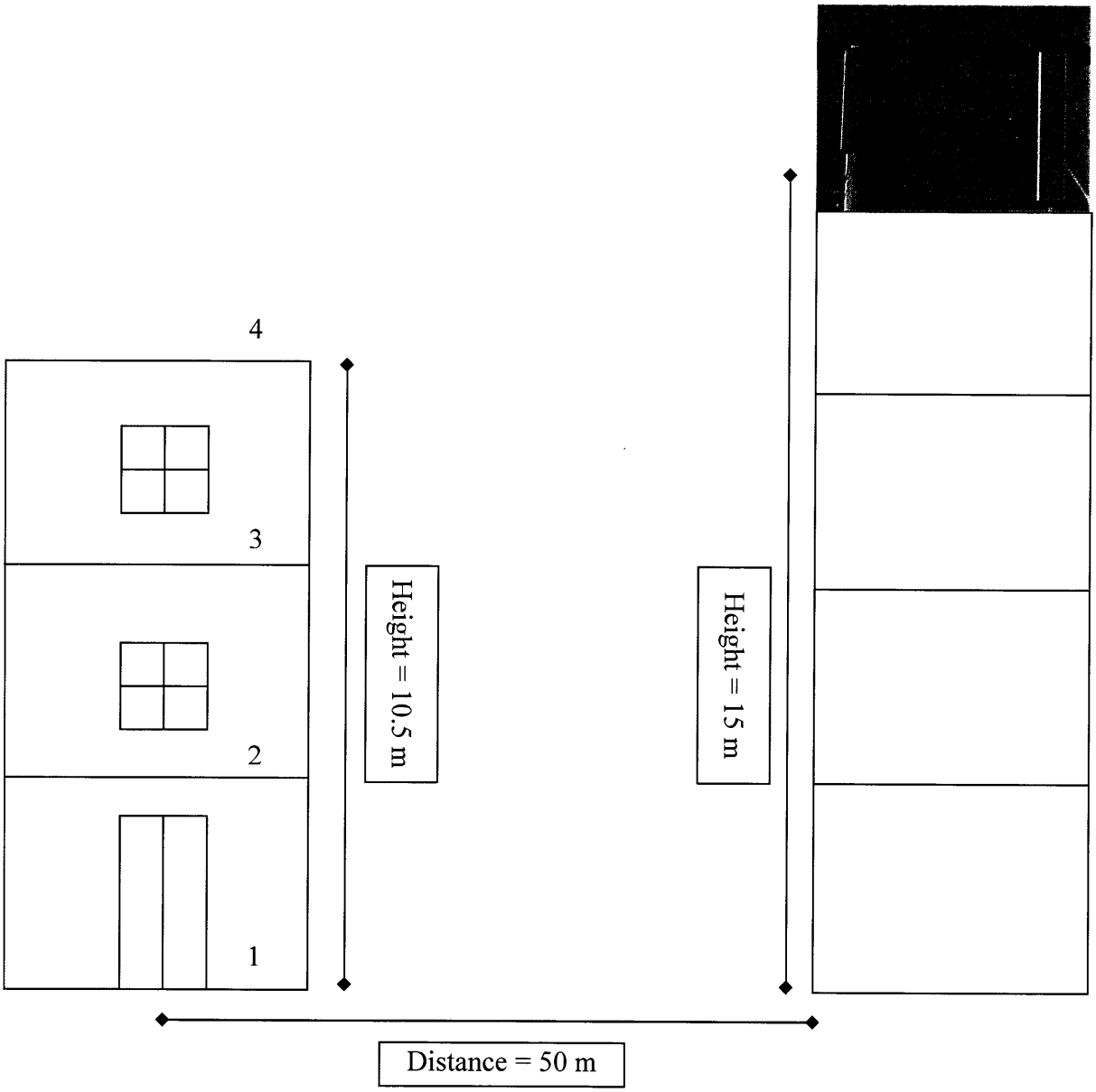


Figure 4: Variation of the power density with horizontal distance at the south of the southern base station at the University of Bahrain.

Appendix 6: The relation between the RF radiation from mobile base station and the vertical distances.



#	Vertical Distance (m)	dBm	Power Density ($\mu W/m^2$)
1	1.5	-28	69.59
2	5	-22	267.64
3	8.5	-15	1330
4	12	-10	4090

Table 1: The variation of power density when the vertical distance changes.

The Abstract in Arabic Language

ملخص الرسالة باللغة العربية

"قياس وتحليل مستويات الإشعاع ذات التردد الراديوي الصادر من محطات الإرسال للهواتف النقالة في مملكة البحرين"

هذه الدراسة هي مسح ميداني لقياس مستويات الأشعة الراديوية الصادرة من عينات لمحطات إرسال الهاتف النقال التي قد يتعرض لها عامة الناس في البحرين. تمت مقارنة مستويات الأشعة الراديوية بحدود التعرض التي وضعتها الهيئة الدولية للحماية من الأشعة غير المؤينة (ICNIRP) – التي تعتمدها منظمة الصحة العالمية– وأيضاً بحدود التعرض المقترحة من قبل قسم التحكم في التلوث في الهيئة العامة لحماية الثروة البحرية والبيئة والحياة الفطرية (PCPMREW) في مملكة البحرين.

حجم عينة محطات الإرسال التي شملتها الدراسة تمثل 25% من المحطات الموجودة (300 محطة). لقد أظهرت النتائج أن الأشعة الراديوية من محطات إرسال الهاتف النقال هي أقل بعشرات المرات من كلا حدي التعرض (ICNIRP) و (PCPMREW)، وإن أعلى مستوى للأشعة الراديوية قد سجل في منطقة السنابس حيث كانت 3400 مايكروواط/م^2 في نطاق GSM900، وهذه القيمة تمثل فقط 0.074% من حد ICNIRP و 3.4% من حد PCPMREW. كما أشارت الدراسة إلى أن متوسط كثافة القدرة لكل محطات الإرسال 577.6 مايكروواط/م^2 والتي تمثل نسبة 0.013% من حد ICNIRP (7964 مرة أقل) ونسبة 0.58% من حد PCPMREW (173 مرة أقل). كما أنه من بين الخمس محافظات في مملكة البحرين، كان أعلى متوسط للإشعاع ذو التردد الراديوي في محافظة العاصمة (884 مايكروواط/م^2) وأقل متوسط كان في المحافظة الوسطى (384 مايكروواط/م^2).

علاوة على ذلك، تم قياس شدة المجال المغناطيسي (H)، بوحدة أمبير/متر، وشدة المجال الكهربائي (E)، بوحدة فولت/متر، وتمت مقارنة القيم المسجلة مع حدود ICNIRP، وقد تبين أنها أقل بكثير من تلك الحدود، ويمكن إعتبارها آمنة. كانت أعلى شدة مجال مغناطيسي وشدة مجال كهربائي تم تسجيلها في هذه الدراسة هي تلك المسجلة في منطقة السنابس ومقدارهما 3 أمبير/متر و 1.133 فولت/متر، على التوالي.

أما بالنسبة للقياسات طويلة الأمد للإشعاع ذو التردد الراديوي (24 ساعة) فقد أظهرت الدراسة أن هناك بعض التغيرات في مستويات هذه الأشعة. إضافة لذلك، فإن تغير مستويات كثافة القدرة للإشعاع الراديوي بين شوارع المنطقة يؤكد قد حجب الأبنية المدنية لتلك الأشعة و تشتتها.

وخلصت الدراسة إلى أن مستويات الأشعة ذات التردد الراديوي المقاسة من محطات إرسال الهاتف النقال في مملكة البحرين هي أقل بكثير عن حدود التعرض لهذه الأشعة الموضوعة من قبل ICNIRP ومن قبل PCPMREW .