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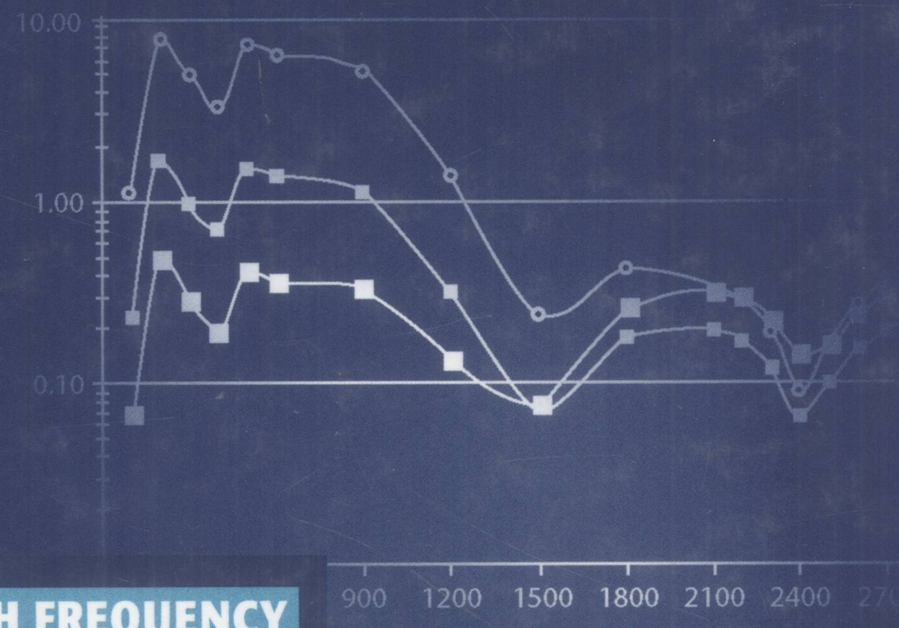

HIGH FREQUENCY

ELECTROMAGNETIC DOSIMETRY

High Frequency Electromagnetic Dosimetry

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Editor

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High Frequency
Electromagnetic Dosimetry

For a listing of recent titles in the
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This book is dedicated to Lucía, Mario, Bruno, Irene, Paula, Marina, Javier, Juan, Pedro, Julia, and Helena, our breed, and to Marien, Sylvia, Marina, Lucía, Ángeles, Ana Belén, Marta, and Ana, our mates and family. They are our daily source of energy for smiling at life.

Foreword

Since the 1990s there has been an explosive growth of mobile communications, with billions of subscribers around the world. Fourth generation systems are bringing broadband wireless internet access to the mobile user. The safety of electromagnetic fields has been the subject of much debate, originally concerned with fields from power lines and more recently with radiated power from handsets, laptops, and base stations. It is an emotive topic and it is important for protagonists on both sides of the debate to make sure that their opinions are drawn from in-depth study of the topic—it is all too easy to pick on the results of one study that confirm a strongly held personal opinion. Sometimes the press can use scientific terms loosely—for example, failing to make the distinction between electromagnetic fields and ionizing radiation is certain to lead to alarm amongst the public. Even specialists in the study of the effects of nonionizing radiation on the human body have differing opinions, and there are varying exposure limits and standards across the world. This is because the study of the effects of high frequency fields on the human body has many facets; frequencies of interest cover a vast range from HF through microwave to THz and infrared. Biological materials have frequency-dependant properties and the human body is not simple to model. The biological interactions may be thermal, from dielectric heating, or more complex nonthermal bioelectromagnetic effects.

It is timely, therefore, to have an extensive treatment of the subject of high frequency electromagnetic dosimetry. The text before you is the result of exhaustive research and includes an excellent overview of the theory and practice of dosimetry systems. Such an authoritative source of information on the science behind, and engineering of, practical dosimetry systems has not been found before in a single volume. You will also find a summary of some of the main opportunities for application of RF and microwave frequencies in medical treatment, from treatment of hypothermia to surgery for cancer therapy. There is no doubt that with a fuller understanding of the interactions between high frequency electromagnetic radiation and the human body, and more precise characterization of such interactions, these applications will develop enormously.

Prof I.D. Robertson
University of Leeds
April 2009

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CHAPTER 1

Introduction

David A. Sánchez-Hernández

1.1 Introduction

Recent decades have witnessed important advances in the technological development of applications with radiofrequency and microwave energy, which have lead to important cost reductions in an ever-increasing number of utilities in industrial, medical, commercial, research, and domestic environments. Nowadays, it is commonplace to find radiofrequency and microwave systems at home, in workplaces, cars, public transport, hospitals, schools, and virtually everywhere else, both outdoors and indoors. The services offered by wired and wireless networks have an ever-increasing complexity. Mobile phones are able to communicate through voice, SMS, pictures, or MMS, and also at high data rate transmissions for financial transactions or even real-time broadband Internet access. This development is seemingly unstoppable, yet at the same time, public fear about possible adverse effects to human health from electromagnetic radiation has also been growing in an exponential increasing reality, with a particular focus on the use of mobile phones and the location of base stations on the top of buildings in urban areas. In spite of social outcry against radioelectric emissions, the use of mobile phones is still exponentially growing around the globe. This is directly reflected in the increasing penetration ratios, with an increasing number of countries witnessing well over 100% penetration ratios in 2008.

The general public receives information about new technologies typically from mass media. Sometimes information with little scientific relevance is presented as important, and it is relatively easy to find press and other media references related to radioelectric emissions and public health, an issue that has become recurrent and seems to remain prominent. As influence of mass media has increased in recent years, so has their responsibility when influencing decision-making procedures [1, 2]. Journalists are normally trained to improve the efficiency when broadcasting, controlling, and selling news to the general public, wherein the main aspects include:

- Facts, basic knowledge, and some correlations are presented in a summarized way—that is, in a black and white image, where gray scales are scarce. Scientific and technological discoveries, however, do not conform well to black and white scenarios as they contain many diverse aspects enriching the discovery in a usually complicated manner. When such discoveries are forced into a simple scenario, sometimes the delivered message is wrong.

- News can be created from opinions, and since the diversity of opinion is enormous, public opinion may change as the news creation process progresses.
- News is presented as an entertainment or amusement tool, and due to the inherent characteristics of leisure, bad news, even that which produces fear, is well received by the general public from the commercial point of view. Yet, the news is slow and inefficient in changing permanent habits, notwithstanding their ability to make people desire what other people or companies with responsibilities have to do.
- This responsibility relocation also happens at the news consuming stage, but with an artificial and virtual distance between the news consumer and the action being described on TV, heard on the radio, or written in the newspaper or on Web pages. Thus, journalists themselves believe their influence on the general public or individuals is not really so important, and that people are clearly able to distinguish between rigorous news and those broadcasted for entertainment.

In this complicated world of roles one has to add, however, that not only a well-trained journalist is required to transmit rigorous scientific news, but also a well-trained scientist/researcher. When delivering biorelated issues, sometimes good journalists have to distinguish between the results of a solo study, which cannot be generalized, and its replica studies, which are the ones from which scientific basis is derived for obtaining conclusions. Yet, the engineering way of doing science is different, and only proven, peer-reviewed and demonstrated facts get published. This diversity, which enriches science from the scientific point of view, makes scientific committees sometimes make decisions by voting, which is not really well understood by the general public or by mass media. Researchers also need to learn on result delivering techniques, not only to scientific and technical journals, which is essential to divulge science and technology, but also in a way that is comprehensible to the general public and the mass media. This includes avoiding technical jargon and complicated descriptions when addressing the mass media. There is certainly a lack of communication and risk perception tools employed in the electromagnetic dosimetry issue. Thus, it is not surprising the feeling of fear that remains in part of the population, who may see the new wireless technologies as a threat.

To date, at frequencies and power levels used in mobile communications systems, any causal relationship between radioelectric exposure and adverse health effects has not been established for a continuous use of less than 20 years. Nevertheless, messages from scientific organizations worldwide that reaffirm this lack of causal-effect data for long-term exposure does not seem to get to people in the same proportion as those other messages with less scientific content and more sensationalist content. Governments, local administrations, and, of course, operators and service providers have the responsibility of introducing into mainstream society the appropriate scientific information about the new systems and technological advances.

The innate nature of science and its way forward does not help at all. In the biomedical scenario, papers get published based upon hypotheses, and need to be replicated long before medical protocols are established and applied over a specific technique. Even when a technique is well established, only practice in the long term can ensure medical feasibility. There are many operational techniques which are discarded by other more recent and scientific ones. This is not well understood by the general public. It is not the intention of researchers to address the general public with scientific publications, but the wide availability of scientific tests cannot be avoided. This sometimes turns into misinterpretation of published results.

The way that epidemiologic science progresses does not help either. When the causal relationship of an effect is not known, it is very important to gather epidemiological data on it. Mankind has obtained many successful advances through observation, such as epidemiologic studies, but the possibility of biasing and the inherent complexity of dealing with statistical data and its boundary conditions over assumptions are not normally considered by the profanes. Observational studies do not adjust to typical laboratory testing, with an absence of random, double blind, and placebo tests, which are considered to be the paradigm of rigorous science based on evidence. It is for this reason that the majority of epidemiological studies include a paragraph about the inherent observational deficiencies.

Among the many available research project results, two recently published ones are of special interest, that of the STROBE and INTERPHONE projects. The international 3-year STROBE project [3] was aimed at reinforcing the rigor on both realization and interpretation of epidemiological studies. Specific detailed descriptions (as detailed as laboratory tests) are recommended, focusing the conclusions to be obtained upon the objective being defined, and identifying critical variables which could lead to different results and interpretation of results. Similarly, reference to similar works both reaching and not reaching the same conclusions are recommended to be included in the study, as well as identifying funding sources and possible conflicts of interest.

A particular study which has been recognized worldwide as state-of-science and well reputed is that of the INTERPHONE project, for which partial results have being published in 2005, 2006, 2007, and 2008. The INTERPHONE project was intended to clarify whether the radiofrequency radiation emitted by mobile telephones is carcinogenic through large-scale transnational epidemiological studies. The project was also intended to avoid the typical sample and ambiguities problems of previous studies and to break new ground. With highly reputed partners and coordinated by the World Health Organization's International Agency for Research on Cancer (IARC), INTERPHONE study results were eagerly awaited. INTERPHONE concentrated on three types of cancer: those associated with the parotid gland, those associated with glial and meningeal brain tissues (gliomas and meningiomas), and those associated with the vestibular part of the eight cranial nerve (acoustic neurinomas). The selection of these types was made because these tumors arise around those tissues that absorb the highest proportion of the RF energy from handheld mobile phones.

Results from INTERPHONE are already available [4–12], but have not clearly solved the issue. The studies on the three tumor types have not provided conclusive results. Not all results were consistent with each other. One study found, among persons who had used cellular phones for 10 or more years, an increased risk for gliomas but not for meningiomas [5]. The increment was found to be of borderline statistical significance [9], and in the conclusions of the project identified to either causal or artifactual due to recall bias [10], related to differential recall between cases and controls [11]. This was reinforced by the fact that the increase was found for ipsilateral use, but a decrease was also found for contralateral use. Most studies did not found an association between use of a mobile phone, either in the short or medium term. Even in the largest of the INTERPHONE national studies published to date there are not enough cases among long-term users to conclude confidently whether or not there is a link between mobile phone use and any type of head or neck cancer. In consequence, in the latest INTERPHONE update, that of February 2008, the IARC reports little evidence in the main analyses for an overall association between mobile phone use and an increase in the incidence of head and neck tumors. The IARC now estimates that INTERPHONE includes approximately 1,100 acoustic-neurinoma cases, 2,600 glioma, 2,300 meningioma and their matched controls. This is considered sufficient to detect confidently a 50% risk increase linked to mobile phone use beginning 5 years or more before enrollment. So the eager anticipation of INTERPHONE's results is not over yet.

Manuscripts presenting results of the international analyses, based on much larger numbers of long-term and heavy users, are in preparation. If no conclusive association is found, then further studies could be questioned. Even if an association could be encountered for ipsilateral use of more than 10 years, the systems employed then (analog) and the power they used is no longer available for the handset. Consequently, the implications for today's technologies could not be determined in a straightforward manner. Some authors are already questioning whether the effects of long-term and analog factors are mixed-up in the first handful of meat-analyses results being published [13]. Moreover, even in these and other international studies, it has been demonstrated that exposure assessment methods have a considerable potential for bias through exposure misclassification and may therefore not be valid in studies investigating possibly subtle changes in risk [8]. In this sense, chance findings are not discarded in some results [6]. Moreover, results from the INTERPHONE study have revealed some concern over researchers regarding the exposure assessment method for the epidemiological study. INTERPHONE researchers [8] have questioned both self-reported findings, based on questionnaire data, and findings based upon subscription data provided by network operators to be good enough to allow a detection of possibly only subtle changes in risk, and they have called for advanced techniques in follow-up studies. Other EU-funded research projects include REFLEX, THz-BRIDGE, CEMFEC, RAMP2001, GUARD, PERFORM-A, PERFORM-B, EMFnEAR, and EMF-NET. These and other non-EU projects are of great interest to biologist, engineers, and physicists, yet they are oriented towards the end-result, which is typically biology oriented.

When studying the role of engineering in the problem, the WHO clearly identified the need to provide for an accurate exposure assessment that has to be repeatable and reproducible. This role was recently reinforced by a recent study on measured results using volunteers [14], jointly performed by ETH Zurich, University of Zurich, and the Nokia Research Center. Results in [14] show a 500% difference when comparing the exposure conditions in different human volunteers. The relationship between exposure values and electromagnetic energy deposed in the body is named "electromagnetic dosimetry." With such a disparity in exposure conditions, the amount of deposed energy for each study could be extremely different. There are already several guidelines about harmonization of electromagnetic dosimetry when performing research on the issue. Even these guidelines have some divergences [15–20]. This poses a big question on the way the scientific problem has been addressed from the electromagnetic dosimetry point of view. It is precisely this role of electromagnetic dosimetry and the vast amount of information in this area that is the seed of this book.

It is the aim of this book to present the recent advances regarding high frequency electromagnetic dosimetry from a scientific and rigorous telecommunications engineering point of view; that is, to obtain advances regarding accurate exposure assessments. The aim is to provide the advanced reader (engineer, scientist, biologist, physicist) with a state-of-science description of the problem at a glance. Most of the potential readers are current scientific leaders in their communities, and many of them are questioned about the issue of EMF and health. While we believe that strong research is the appropriate way to understand the issue, this book is intended for those researchers, scientists, and engineers who are not doing research in the field but are interested in knowing more about it. In addition, any researcher would welcome the availability of an up-to-date compilation text like this one. Readers must not expect, however, detailed biological experiments and results, as only high frequency electromagnetic dosimetry is the key issue of the book. By understanding EMF dosimetry, biological experiments may be made repeatable and comparable, which is a must for science to progress.

1.2 Exposure Scenarios

Two different exposure scenarios can be distinguished for mobile communications systems: that of the human head, due to the near-field radioelectric emissions from handsets, and the exposure of the general public or workers due to radioelectric emissions from base station antennas. Exposure to base station radioelectric emissions typically occur in the far-field, but it may also take place in the near-field. The diverse techniques and technical specifications limit the power transmitted by a mobile handset today, but the wide variety of commercial units and their use patterns make the analyses of human interaction with electromagnetic waves a complicated task depending upon many different variables. The fundamentals of electromagnetic field interaction with matter will be covered in Chapter 2.

Due to both the popularity of mobile phone use and also the focusing effect of EMF-related risk perception issues on base station antennas and mobile handsets, it has received much more scientific attention than other sources of radioelectric emissions. Measurements carried out over mobile networks up to date all around the world have demonstrated that electromagnetic field levels for the general public at the street level, emitted by base stations transmitters, are some orders of magnitude lower than maximum permissible levels. Electromagnetic dosimetry associated with emissions from mobile phones, on the other hand, is higher than that from base stations due to their proximity to the user, and power limitations have been derived specifically for mobile handsets. Since mobile phones emit electromagnetic waves very near of the user's head and cause a complex exposure environment which is difficult to measure, this problem has received more attention than that of the base station scenario. As it will be described in this book, both problems are equally complex and several different factors have to be taken into account for accurate and rigorous exposure assessment. Yet, while many references can be found in the scientific literature for the handset scenario, the base station scenario has not received comparable attention, and further, particular references to third generation systems are scarce.

For the handset scenario, all mobile phones to be commercialized in the European Union or the United States have to undergo strict quality tests, including several wherein specific absorption rate (SAR) levels are evaluated and results have to conform to frequency-dependent preestablished safety limits. In the European Union the SAR evaluation results are normally provided by the manufacturer, while in the United States the Federal Communications Commission (FCC) regularly publishes the results so that users are well aware of this parameter when acquiring their units. For the base station scenario, maximum SAR values have been observed in regions of the human body like the chest or the back [21–23], different to those encountered for the first scenario, mainly due to either direct exposure or to reflections on nearby walls or buildings. In [21], for instance, three different user positions were studied, always at far-field distances, providing peak SAR values of 12.9, 8.2, and 2.45 mW/g, averaged over 1g, 10g, and the whole body, respectively, which is well below the limits recommended by the European Council. A 20-cm safety distance was established in [23] for several GSM1800 base station antennas with an input CW power of 10W when a person was located directly in front of the antenna's main beam. Depending upon the specific EMF limit under study, near-field safety distances between 1 and 65 cm were found in [24] using automated scanning systems. These systems will be described in Chapter 6.

In absolute terms, electric field levels emitted from base stations and evaluated as reference levels on human beings on the street are lower than those from mobile phones. Yet, the concern about base stations is greater than that of mobile phones. The explanation is simple: The nature of both elements is different. People can decide whether or not to use a mobile phone and which one they prefer, but nothing can be decided as far as general public is concerned about the installation of a base station near their home. In addition, people are well aware of the direct benefits of a mobile phone, but they do not perceive the same benefits from a base station installed at a few meters away from their homes. On the contrary, this base station can be the origin of their anxiety or even devaluate the price of their houses, which may be the cause for some of their real feelings, and it is certainly the subject of recent studies. With these arguments, it is understandable that people fiercely oppose the installation of new base stations in the vicinity of their houses, supported by something that can or cannot be guaranteed by scientific investigations. Far- and near-field numerical electromagnetic dosimetry will be explained in Chapters 3 and 4, respectively. Chapter 5 will describe in situ measured exposure assessment and compliance testing.

1.3 The Nature of the Interaction: Rationale for Limiting Exposure to EMF

Human beings have lived with natural radioelectric emissions from the beginning of time, and with artificial radioelectric emissions for more than one century, starting when Guglielmo Marconi invented the wireless telegraph. Microwaves and radioelectric emissions are presented in nature from the Sun, galaxies, and our own planet Earth. The Earth's biosphere is characterized by its electric and magnetic fields and also by atmospheric discharges. Any body with a temperature higher than 0K (−273°C) emits electromagnetic radiation as a result of the accelerations suffered by charged particles due to thermal vibration. This is known as the body's thermal radiation. For example, the Earth emits a power density of up to 0.3 mW/cm^2 at 300 GHz, assuming an averaged temperature of 293K (20°C). Of course, the human body has a temperature higher than 0K, which means that it emits electromagnetic energy of around 0.3 mW/cm^2 within the frequency range of 10 kHz to 300 GHz. Interest in the incidence of this kind of emissions on human health began with the development of the first artificial radioelectric systems. Since then some scientific organizations and institutions have investigated the possible effects (positive, innocuous, and negative) associated to the interaction of electromagnetic waves with human beings, animals, and the environment. Radioelectric emissions from mobile phones and base stations are just part of the story, but they can be evaluated and verified by measurement techniques and procedures established with general character with any source of radioelectric emission.

It is well known that exposure to high intensity electromagnetic fields produces biological effects [25]. The diverse recommendations and guidelines established by international scientific committees share the same basis for the setup of a peak SAR limit averaged over the whole body so that exposure does not pose a threat to human health. It was shared knowledge that adverse behavioral effects could be observed in primates for exposure rates over ~4 W/kg [25]. This limit was associated with the body thermal increment which could not be coped with by the primate's thermoregulatory system. Assuming similar coupling mechanisms in human beings, a safety factor of 10 was established for workers (occupational exposure), and an additional factor of 5 (making a total of 50) for the general public, thus deriving the SAR limit of 0.08 W/kg, averaged over the whole body. These factors are intended to cover different situations, like preheated situations during exercise, increased thermal environment, humidity, thermal conditions in infants, sensitive people, or even the ingestion of drugs and alcohol. Before the guidelines were developed in the European Union and the United States, some experiments on human volunteers were performed, and this ~4 W/kg value was confirmed to produce body thermal increments less than 1°C. This already established averaged thermoregulation capacity for humans was reaffirmed as the correct threshold [26], although temperature measurements were only performed in the surface.

Yet, while it is possible to be exposed at frequency values for which only parts of the body are resonant, as in the mobile communications scenario, local temperature increments and SAR values could well exceed those of the limit, yet the whole-body averaged value would not be surpassed and rectal temperature (assumed to equal core body temperature) may remain constant. These minor incre-