Electromagnetic Fields of Wireless Communications: Biological and Health Effects

EDITED BY

Dimitris J. Panagopoulos

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Electromagnetic Fields of Wireless Communications: Biological and Health Effects

This book reflects contributions from experts in the biological and health effects of Radio Frequency (RF)/Microwave and Extremely Low Frequency (ELF) Electromagnetic Fields (EMFs) used in wireless communications (WC) and other technological applications. Diverse topics related to physics, biology, pathology, epidemiology, and plausible biophysical and biochemical mechanisms of WC EMFs emitted by antennas and devices are included. Discussions on the possible consequences of fifth generation (5G) mobile telephony (MT) EMFs based on available data and correlation between anthropogenic EMF exposures and various pathological conditions such as infertility, cancer, electro-hypersensitivity, organic and viral diseases, and effects on animals, plants, trees, and environment are included. It further illustrates individual and public health protection and the setting of biologically- and epidemiologically-based exposure limits.

Features:

- Covers biological and health effects, including oxidative stress, DNA damage, reproductive effects of mobile phones/antennas (2G, 3G, 4G), cordless phones, Wi-Fi, etc.
- Describes effects induced by real-life exposures by commercially available devices/antennas.
- Illustrates biophysical and biochemical mechanisms that fill the gap between recorded experimental and epidemiological findings and their explanations.
- Explores experimental and epidemiological facts and mechanisms of action. Provides explanations and protection tips.
- Transcends across physical, biological, chemical, health, epidemiological, and environmental aspects of the topic.

This book is aimed at senior undergraduate/graduate students in physics, biology, medicine, bioelectromagnetics, electromagnetic biology, non-ionizing radiation biophysics, telecommunications, electromagnetism, bioengineering, and dosimetry.

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Contents

The Editor

Dr. Dimitris J. Panagopoulos (electromagnetic fields – biophysicist) was born in Athens, Greece, where he lives and works. He has a degree in Physics and a PhD in Biophysics both from the National and Kapodistrian University of Athens (NKUA). He completed his PhD on the Biological Effects of Electromagnetic Fields (EMFs) in 2001, and two post-doctoral studies on the biological effects of microwaves (2004) and on cell death induction by wireless communication (WC) EMFs (2006). He worked as a post-doctoral researcher and lecturer at the Department of Cell Biology and Biophysics, NKUA, (2002–2014), where he gave undergraduate and graduate lectures on radiation and EMF biophysics and performed research on the effects of various types of EMFs in experimental animals. From 2014 to 2018, he worked as a research associate at the National Centre for Scientific Research "Demokritos", Laboratory of Health Physics, Radiobiology, and Cytogenetics, researching effects of ionizing and non-ionizing radiation on human cells. Since 2018, he has been working as a researcher at the Choremeion Research Laboratory, Medical School, NKUA. His experiments were among the first that showed damaging effects of man-made EMFs on DNA and reproduction. He has also shown beneficial effects on reproduction of EMFs that mimic natural ones. His theory on the biophysical mechanism of action of EMFs on cells is considered the most valid amongst all proposed theories and is cited by more than 700 scientific publications. This theory has explained the sensing of upcoming earthquakes by animals and the sensing of upcoming thunderstorms by sensitive individuals through the action of the natural EMFs associated with these phenomena. The same theory has recently explained the induction of oxidative stress in cells by EMF exposure. Dr. Panagopoulos has shown why the specific absorption rate (SAR) is not a proper metric for non-thermal effects; why man-made (totally polarized and coherent) EMFs are damaging, while natural EMFs are vital; and why highly varying real-life exposures from mobile phones and other WC devices are significantly more damaging than simulated exposures with invariable parameters. He has also shown that genetic damage caused by WC EMFs occurs similarly in human and animal cells. Dr. Panagopoulos has also argued that photons are strictly wave-packets, not particles of light, and that man-made electromagnetic radiation does not consist of photons but of continuous "classical" polarized waves, in contrast to what has been postulated by quantum physicists for the past 100 years. He is the first or sole author in more than 40 peer-reviewed highly influential scientific publications, which have been referenced more than 1,800 times by other scientific publications and has been included in the Top 10 cited authors by the *Mutation Research* journals.

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† We regret to announce that our teacher, colleague, coworker and friend, Dr. Constantinos Lioliousis, Professor at the Department of Physics of the National and Kapodistrian University of Athens, who distinguished himself in the fields of applied physics, microwave electronics, telecommunications, and biological effects of electromagnetic fields, and contributed to this book as a coauthor in Chapter 1, a brilliant scientist and a man of ideals and integrity, passed away soon after the completion of the chapter, at his 82 years. Chapter 1 of this book, which represents his final contribution, is dedicated to his memory.

Foreword

Information and communication technology is an ever-evolving medium which has penetrated all aspects of life as we know it, accruing unprecedented societal benefits. But with those benefits come risks that need to be managed, and this book presents an exceptional, fact-based foundation for the latter.

Originally developed as a military tool, the wireless aspects of information and communication technology are complex and multi-faceted, with nuances unique to each type of mobile or cordless device, infrastructure platform, and exposure character, with effect metrics driven in large part by the sophisticated interplay of genetics and epigenetics.

To fully understand the depth and breadth of wireless technology and its health implications takes time, intelligence, and longitudinal effort. The growing scientific literature on wireless technology's biological activity alone includes thousands of peer-reviewed papers. The tasks of both learning this field and integrating the many strands of emerging knowledge portend multiple years of commitment.

In a time when opinions, informed and not, are readily available through multiple journalistic, entertainment, and social media platforms, the attainment of factual truth is elusive. But it is only factual truth that can ensure societal decision-making that is both reliable and actionable. Therein lies the value of this coalescence of professional factual thinking put forth here by Dr. Panagopoulos and his colleagues that represent a cross section of the world's top scientists and their work on the biological impacts of wireless communications technology.

This book effectively and efficiently presents the critically important science that leads to informed decisions about health, safety, and the environment. All the critical scientific aspects are considered in a learned fashion on these pages, presented by scientists who do the actual work, and who have done the heavy lifting of sorting and integrating these complexities for practical application.

This book is a necessary factual truth resource for scientists looking to informedly pursue wireless communications subject matter; for responsible employers looking to protect those in their workplaces; for regulators looking to protect health and the environment; for clinicians looking to do the best for their patients; for policy-makers looking to make informed changes to ensure public safety; and for consumers looking to balance the benefits of technology with protections for their children, families, and friends.

Read this book. Absorb its contents. Believe it. And be comfortable acting on this knowledge.

Dr. George L. Carlo
Washington, DC, USA
December 2022

Introduction

Abbreviations: B-field: magnetic field. E-field: electric field. EHS: electro-hypersensitivity. ELF: Extremely Low Frequency. EMF: electromagnetic field. EMR: electromagnetic radiation. LF: Low Frequency. MT: mobile telephony. MW: Microwaves. NR: New Radio. OS: oxidative stress. RF: Radio Frequency. ROS: reactive oxygen species. SAR: Specific Absorption Rate. ULF: Ultra Low Frequency. VGIC: voltage-gated ion channel. VLF: Very Low Frequency. WC: wireless communications. Wi-Fi: Wireless Fidelity. 1G/2G/3G/4G/5G: first/second/third/fourth/fifth generation of MT.

Static electric (E) fields are generated by (macroscopicaly) standing electric charges (actually nothing is "standing" at microscopic level), and static magnetic (B) fields are generated by direct and constant electric currents (directional movement of electric charge with a constant velocity). Only static (invariable in time) E- or B-fields can each exist alone without the coexistence of the other. But again, nothing is absolutely invariable in time, and, thus, totally static, and single E- and B-fields exist only approximately in certain occasions, such as electric fields of "isolated" charged objects or of electric batteries and magnetic fields of certain minerals (magnets).

When electric charges oscillate back and forth (as e.g., in alternating electric currents), both E- and B-fields are generated that also oscillate in phase with the charges. Thus, oscillating electric charges generate oscillating E- and B-fields simultaneously, and the frequency of the generated fields is the same as the frequency of the oscillating charges. The generated E-field oscillates in parallel to the direction of charge oscillation, while the generated B-field oscillates vertically to this direction. Due to this strong interrelation and coexistence between oscillating electric and magnetic fields, we talk about electromagnetic fields (EMFs). Oscillating electric and magnetic fields are not only generated simultaneously by oscillating electric charges but also the one reproduces the other each moment, and the two of them (vertical to each other) can propagate in space in the form of electromagnetic waves or electromagnetic radiation (EMR) vertically to both of them. Thus, electromagnetic waves are E- and B-fields oscillating with the same frequency vertically to each other and vertically to the direction of their propagation. The plane of oscillation of the E-field is called the polarization plane of the wave. The frequency of the emitted EMR is the same as the frequency of its oscillating fields and the oscillating charges that generate them. Thus, oscillating E-/B-fields not only create each other and always coexist, but they also have the unique property to reproduce and propagate themselves in the surrounding space, even in the absence of a material medium, i.e. in the vacuum. All electromagnetic waves propagate with the velocity of light, which is different in each medium. The velocity of light (and of any electromagnetic wave) in the vacuum or in the air (measured by the pioneer physicist H. Hertz to be approximately equal to ($\approx$) 3×10^8 m/s) represents an upper limit for all known velocities of any material or energetic entities (Tesla 1905; Alonso and Finn 1967; Jackson 1975).

In nature, all electric charges oscillate in all possible directions, and the generated EMFs/EMR have similarly random polarizations; in other words, they are not polarized, apart from specific occasions that are locally and partially polarized. Moreover, they do not oscillate with a unique frequency and in phase (coordinately). By contrast, electric charges in electric/electronic circuits oscillate in unique directions (determined by the geometry of the metallic conductors) and coordinately (with a unique frequency and phase), and, thus, the generated technical (man-made) EMFs/EMR are totally polarized and coherent (Panagopoulos et al. 2015a). All anthropogenic EMFs/EMR oscillate at subinfrared frequencies (0–3×10^{11} Hz) (Figure 0.1).

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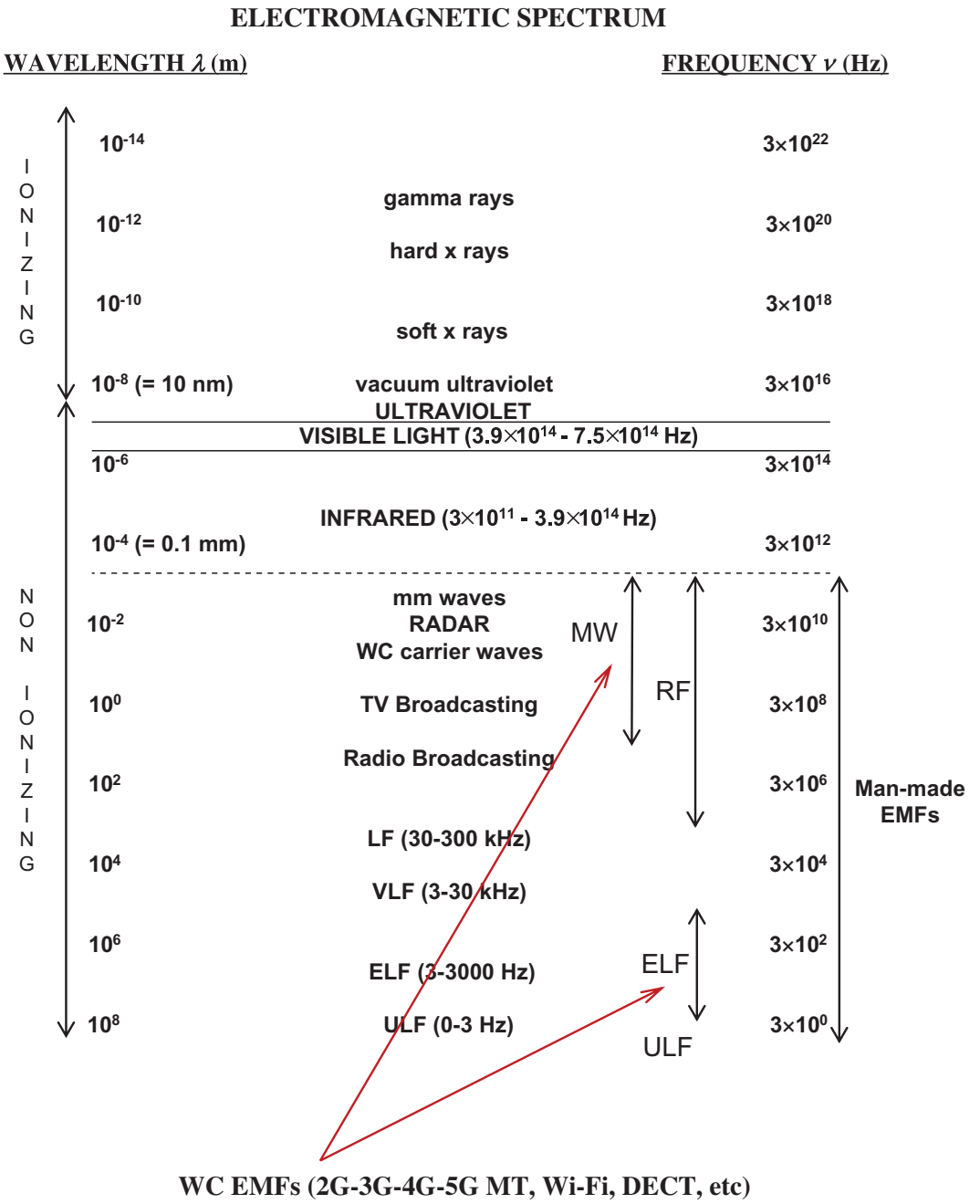

FIGURE 0.1 The electromagnetic spectrum with the ionizing, visible, infrared, and subinfrared parts. Man-made EMFs occupy the subinfrared frequency range (0–3 × 10^{11} Hz), and WC EMFs always combine MW carrier frequencies with ELF modulation and pulsation. Natural EMFs in the subinfrared part of the spectrum are cosmic microwaves, atmospheric EMFs due to lightning discharges (VLF, ELF), Schumann resonances (ELF), spontaneous ionic oscillations in cells (ULF), etc.

During the past five decades and beyond, a great amount of scientific knowledge has been accumulated regarding the biological and health effects of man-made EMFs and corresponding EMR. High-voltage power transmission lines and transformers operating at the Extremely Low Frequency (ELF) (3–3000 Hz) band, specifically at the so-called power frequency (50–60 Hz), radars, and various types of analog transmitters operating at the Radio Frequency (RF) (300 kHz–300 GHz) band and in its highest part called Microwave (MW) band (300 MHz–300 GHz) (Figure 0.1), were the first powerful man-made EMF/EMR sources that attracted the attention and concern of scientists and physicians for their biological/health effects (Persinger 1974; Presman 1977; Marino and Becker 1977; Adey 1981; 1993; Goodman et al. 1995; Puranen and Jokela 1996).

This accumulated knowledge is of particular importance today, as wireless communications (WC) have become an important part of daily life. In WC technologies, the information is conveyed by electtromagnetic waves transmitted by devices and corresponding antennas. Today's digital WC technological products include mobile phones and corresponding mobile telephony (MT) base antennas; cordless domestic phones; wireless Internet connections called Wi-Fi (Wireless Fidelity); wireless connections among electronic devices (called "Bluetooth"), etc. All digital WC devices and corresponding antennas emit MW carrier waves that are necessarily modulated and pulsed by low frequency (mostly ELF) signals in order to carry variable information and provide simultaneous service to many users. The levels of EMF emissions from WC and other technologies have increased exponentially, especially during the past 25–30 years that digital WC are in use and, similarly, the human exposure to these EMF emissions. This tremendous increase of human exposure to EMFs is an unprecedented phenomenon throughout the billions of years of biological evolution. Most importantly, as explained already, all anthropogenic EMFs differ significantly from the natural EMFs in that they are totally polarized and coherent. Therefore, living organisms are not expected to have natural defenses against anthropogenic EMFs.

While the first-generation (1G) mobile phones in the 1980s were analog and of limited use, digital MT technology since the mid-1990s has evolved fast by producing the existing second, third, and fourth generations (2G/3G/4G) of devices/antennas with each next generation transmitting increasing amounts of information/data (voice, text, pictures, video, Internet). Today the massive deployment of the New Radio (NR) 5G (fifth generation) MT/WC system around the world by the telecommunications industry, which is expected to further increase considerably the existing ambient EMF levels, has already started and is rolling out, despite serious concerns expressed by scientists (Miller et al. 2018; 2019; Hardell and Nyberg 2020; Kostoff et al. 2020; Levitt et al. 2021). At the same time, during the past 2 years, humanity was suddenly confronted by a pandemic due to a new virus. As a result, a lot of concern has been raised among scientists and the general population regarding the health and environmental consequences of a vast technological expansion that is taking place uninvited to such an extend.

Natural EMFs/EMR in the terrestrial environment (geoelectric and geomagnetic fields, atmospheric discharges, Schumann resonances, solar light, cosmic microwaves, gamma radiation, etc.) are never totally polarized and maintain relatively constant average intensities. Those that are locally polarized, to a significant degree, are static with constant polarities, such as the geoelectric and geomagnetic fields (with average intensities approximately (~) 130 V/m and ~ 0.05 mT, respectively). Similarly, static and locally polarized are the cell membrane fields (~ 10^7 V/m). During short-term changes of 20%–30% in the average constant intensities of both the environmental and the cell membrane natural EMFs, health problems and biological effects respectively are initiated (see Chapter 1 and Presman 1977; Dubrov 1978; Panagopoulos 2019). This fact suggests that the combination of polarization and variability provides a basis for EMF bioactivity (Panagopoulos 2019).

Now, all man-made EMFs produced by electric/electronic circuits are totally polarized and oscillating, and especially modern digital WC EMFs vary greatly and unpredictably at all times displaying, apart from the ELF pulsing and modulation mentioned already, significant random variability, mainly in the Ultra Low Frequency (ULF) (0–3 Hz) band, with intensity variations usually exceeding by more than 30% (and even by more than 100% in many instances) the average values because

of the varying information they transmit and many other factors (see Chapter 1 and Panagopoulos 2019). These significant physical differences between natural and man-made EMFs explain their corresponding differences in the induced biological/health effects.

Natural EMFs are necessary for maintaining the health and wellbeing of all living organisms on Earth. A characteristic example is the atmospheric "Schumann" resonances that attune the brain electrical activity in all animals (Persinger 1974; Wever 1979; Cherry 2002; 2003; Panagopoulos and Chrousos 2019). By contrast, man-made EMFs have been found to produce a great number of adverse biological and health effects. These include changes in key cellular functions; oxidative stress (OS); DNA and protein damage; cell death; infertility; cancer; effects on the immune system; changes in human/animal physiology, such as brain activity; pathological symptoms referred to as electro-hypersensitivity (EHS); etc. (Adey 1981; 1993; Liburdy 1992; Walleczek 1992; Goodman et al. 1995; Santini et al. 2005; Phillips et al. 2009; Hardell and Carlberg 2009; Khurana et al. 2009; De Iuliis et al. 2009; Johansson 2009; Szmigielski 2013; Houston et al. 2016; Yakymenko et al. 2011; 2016; 2018; Mohammed et al. 2013; Balmori 2015; 2021; Gulati et al. 2016; Zothansiama et al. 2017; Miller et al 2018; 2019; Panagopoulos 2019; 2020; Irigaray et al. 2018; Belpomme and Irigaray 2020). From all anthropogenic EMF types, WC EMFs seem to be the most adversely bioactive, mainly because of their increased variability (Panagopoulos 2019).

Under the weight of accumulating scientific evidence, the International Agency for Research on Cancer (IARC), which is part of the World Health Organization (WHO), has categorized both ELF and RF (in fact WC) man-made EMFs as possibly carcinogenic to humans (IARC 2002; 2013). More recent updates on human cancer epidemiology and animal carcinogenicity studies argue that WC EMFs should be categorized as "probably carcinogenic" or "carcinogenic" (Miller et al. 2018; 2019; NTP 2018; Falcioni et al. 2018; Hardell and Nyberg 2020).

Significant scientific evidence shows that the bioactivity of WC EMFs is mainly due to their ELF/ULF components and that RF/microwave carrier signals alone, without modulation, pulsing, and variability, do not usually induce biological effects other than heating at adequately high intensities and frequencies (Bawin et al. 1975; 1978; Blackman et al. 1982; Frei et al. 1988; Walleczek 1992; Bolshakov and Alekseev 1992; Goodman et al. 1995; Penafiel et al. 1997; Creasey and Goldberg 2001; Huber et al. 2002; Betti et al. 2004; Goldsworthy 2006; Höytö et al. 2008; Franzellitti et al. 2010; Campisi et al. 2010; Mohammed et al. 2013; Panagopoulos 2019). As summarized by Goldsworthy (2006), "it is widely accepted that continuous unmodulated radio waves are of too high a frequency to give biological effects but they do become effective when pulsed or amplitude modulated at a low frequency". All endogenous physiological EMFs discovered so far within living organisms, such as the intracellular spontaneous ionic oscillations, the endogenous electric currents that control all cellular and tissue functions, or the electromagnetic signals of brain and heart activities, oscillate at low frequencies (ELF/ULF). And then, like in all forms of matter, molecular oscillations and thermal noise have frequencies in the infrared band. RF EMFs have not been detected in living organisms (Alberts et al. 1994; McGaig and Zhao 1997; Huber et al. 2002; Nuccitelli 2003; Mohammed et al. 2013). It is, thus, absolutely expected for living organisms to be more responsive to external EMFs of similar frequencies. Although this notion for the principal role of ELFs in the bioactivity of WC EMFs has long been available and repeatedly verified, many studies focus exclusively on the RF part of the WC EMFs. A most common problem in published reports on the effects of WC EMFs is that many of them refer to these EMFs simply as "RF" or "microwave", without assessing or even mentioning the inevitable coexistence of ELFs, which are actually the most bioactive (Pakhomov et al. 1998; Betskii and Lebedeva 2004; Belyaev 2005; EPRS 2020; 2021; Karipidis et al. 2021).

Recently, because of the highest microwave carrier frequencies ("mm-waves") of the 5G, certain Russian studies reporting "non-thermal effects of microwave/mm-wave EMFs" came to light. These studies were written in Russian and became known mostly from reviews in English by other Russian scientists. Three such reviews are by Pakhomov et al. (1998), Betskii and Lebedeva (2004), and Belyaev (2005). In several studies reviewed in Pakhomov et al. (1998) and Belyaev (2005), ULF/ELF and Very Low Frequency (VLF) (3–30 kHz) components were present in the form of pulsing

and/or modulation/intermittence/variability, while no information on possible existence of such components was provided in the rest of the reviewed studies. Similarly, in the Betskii and Lebedeva (2004) review, information on possible existence of low-frequency components (ULF/ELF/VLF) is absent throughout the paper, but their presence was again not excluded. As it is unlikely that any microwave electronic circuit/generator is not turned on and off, even only for energy-saving reasons, the existence of ULF/ELF/VLF components, and the separate roles of the low and high frequencies in the biological effects, need to be carefully addressed in all experimental studies employing RF/microwave EMF exposures and in the related reviews in order to prevent misleading conclusions. This can be done easily and reliably in experimental studies by performing and reporting electric and magnetic field measurements in the ELF band by ELF field meters and/or spectrum analyzers. Thus, all experimental RF/microwave studies should necessarily include such measurements, and review studies should necessarily report the ELF components in the various exposures.

While one effect induced by high intensity (>0.1 mW/cm^2) and frequency (≥1 GHz) microwave EMFs is that of heating exposed materials and living tissues (as happens in microwave ovens with food) ("thermal effects") (Metaxas 1991; Goodman et al. 1995; Creasey and Goldberg 2001), the vast majority of the recorded biological/health effects at lower – environmentally relevant – intensities (from either RF/WC or purely ELF EMFs) are not accompanied by any significant temperature increases and, thus, have been categorized as non-thermal effects (Goodman et al. 1995; Belyaev 2005; Panagopoulos et al. 2013; Yakymenko et al. 2016). Still, the metric for RF EMF bioactivity suggested by health agencies is the Specific Absorption Rate (SAR) (IARC 2013), which, apart from the fact that it is impractical because it cannot be measured directly but has to be calculated (usually by simplistic and inaccurate methods), actually accounts only for thermal effects because the only reliable way to estimate it is by measuring temperature increases (see Chapter 1 and Gandhi et al. 2012; Panagopoulos et al. 2013).

While man-made EMFs cannot directly break chemical bonds and, thus, cause direct ionization of molecules, they are capable of inducing such effects indirectly, by triggering production of free radicals and reactive oxygen species (ROS) in the cells (De Iuliis et al. 2009; Burlaka et al. 2013; Pall 2013; Houston et al. 2016; Yakymenko et al. 2016; 2018; Zothansiama et al. 2017; Panagopoulos et al. 2021). Such species can damage any critical biomolecules, including DNA. The (over)production of ROS in cells and the consequent OS that arises can be triggered by irregular gating of voltage-gated ion channels (VGICs) in the cell membranes due to purely ELF/VLF man-made EMFs or the ULF/ELF/VLF components of the complex WC EMFs (Creasey and Goldberg 2001; Panagopoulos et al. 2002; 2015a; 2021). Today, irregular gating of VGICs in cell membranes by man-made EMFs has been verified by many experimental studies (e.g., Liburdy 1992; Piacentini et al. 2008; Cecchetto et al. 2020; Zheng et al. 2021) and presented by reviews (Pall 2013; Bertagna et al. 2021). Thus, we are dealing with mechanisms that result in chemical changes of critical biomolecules without heating the exposed biological tissues.

Although the majority of peer-reviewed published studies (more than 60%–70%) indicate effects of purely ELF man-made EMFs for field intensities down to less than a few V/m or a few μT, or of pulsed/modulated RF/WC EMFs for RF intensities down to less than 1 μW/cm^2 even for short-term exposures (Goodman et al. 1995; Santini et al. 2005; Phillips et al. 2009; Panagopoulos et al. 2010; Szmigielski 2013; Burlaka et al. 2013; Manna and Ghosh 2016; Yakymenko et al. 2011; 2016; Leach et al. 2018; Panagopoulos 2019), health authorities responsible for setting exposure guidelines in most countries have adopted limits that are thousands (and even millions, in some cases) of times higher, as set by a private, non-governmental organization (NGO) called the International Commission on Non-Ionizing Radiation Protection (ICNIRP 1998; 2010; 2020; Hardell and Carlberg 2021). These limits may provide limited protection against thermal RF effects, but certainly not against the non-thermal effects of the purely ELF man-made EMFs or the ELF components of the complex RF/WC EMFs, which actually constitute the vast majority of the reported biological and health effects.

Indicative threshold EMF/EMR intensity levels found to induce significant (non-thermal) biological/health effects and the corresponding ICNIRP (2010; 2020) limits for public exposure in the ELF and RF bands are shown in Table 0.1. It is evident that serious biological and health effects

TABLE 0.1
Threshold EMF/EMR Intensities for Indicative Biological/Health Effects and Corresponding ICNIRP Limits

Incident EMF	ICNIRP Intensity Limit (6 min Average, Local Exposure)	Threshold Intensity for Effect Initiation	Exposure Duration	Effect	References
ELF-E (CW or pulsed) (1–50 Hz)	5000 V/m	0.002 V/m	12 h	Decrease in protein synthesis rate	McLeod et al. (1987)
		0.0021 V/m	4 days	Increase in DNA synthesis rate	Cleary et al. (1988)
		10 V/m	Years	Cancer (humans)	Coghill et al. (1996)
ELF-B (50 Hz CW)	2 G (200 μT)	0.002 G (0. 2 μT)	Years	Cancer (humans)	Feychting and Ahlbom (1994)
Pulsed RF (GSM) 1800 MHz	3655.6 $\mu W/cm^2$	<1 $\mu W/cm^2$	6 min/day, 6 days	DNA damage, cell death (fruit fly ovarian cells)	Panagopoulos et al.. (2010)
Pulsed RF (GSM) 900 MHz	2014.0 $\mu W/cm^2$	0.25 $\mu W/cm^2$	158–360 h intermittently	OS, DNA damage, embryonic death (bird embryos)	Burlaka et al. (2013)
Pulsed RF (GSM) 1800 MHz	3655.6 $\mu W/cm^2$	0.32 $\mu W/cm^2$	19 days (48 s On/12 s Off)	OS, DNA damage, embryonic death (bird embryos)	Yakymenko et al. (2018)

[ICNIRP (2020) limits calculated for 900 and 1800 MHz according to formula: $0.058f_M^{0.86}$. CW: continuous-wave. G: Gauss].

such as OS, DNA damage, cancer, etc. may occur from exposure to ELF EMFs or WC EMFs at levels thousands of times lower than the corresponding ICNIRP limits, while more subtle cellular effects may be initiated at ELF thresholds more than a million times lower than the corresponding ICNIRP limits (McLeod et al. 1987; Cleary et al. 1988; Feychting and Ahlbom 1994; Coghill et al. 1996; Panagopoulos et al. 2010; Burlaka et al. 2013; Yakymenko et al. 2018). Hence, these limits do not provide any health protection.

Because of these facts, and regardless of our remaining knowledge gaps, health complaints are increasing, especially among people residing close to antennas or high-voltage power lines, accompanied by increasing cancer rates and symptoms of unwellness (Kundi and Hutter 2009; Gulati et al. 2016; Zothansiama et al. 2017; Miller et al. 2018; 2019; Belpomme and Irigaray 2020; Lopez et al. 2021).

The situation may seem confusing with several other studies reporting no effects of ELF or pulsing/modulated RF/WC EMFs, especially studies that have employed simulated WC EMF exposures from generators, "exposure chambers", or "test" mobile phones with invariable parameters (carrier frequency, intensity, pulsations) and no modulation (ICNIRP 1998; 2020; IARC 2002; 2013; EPRS 2020; 2021; Karipidis et al. 2021). Indeed, about 50% of the studies that employ simulated EMFs do not find effects. In contrast, among studies that employ real-life exposures from commercially available devices with high variability (such as mobile or cordless phones, Wi-Fi, etc.), more than 95% find effects (Panagopoulos et al. 2015b; Yakymenko et al. 2016; Leach et al. 2018; Panagopoulos 2019; Kostoff et al. 2020).

Bioelectromagnetics is a complex scientific field, featuring an equal combination of physics and biology. This is why collaboration among experts from different areas (e.g., physicists with biologists, or medical doctors with engineers) is necessary. EMF bioeffect experiments must necessarily be carried out by scientists/teams that combine adequate knowledge in both the physical and the biological parts; otherwise, the methodology may be flawed and the conclusions misleading. The use of any devices such as generators and exposure chambers provided by companies for exposure of biological samples to simulated EMFs without knowing and measuring the physical details of the generated EMFs is a major flaw in experimental studies.

Unfortunately, conflict of interest, corruption, results depending on funding, and misleading information in scientific papers have become usual phenomena in the field (Hardell and Carlberg 2021; Leach et al. 2018). Conflict of interest is not necessarily limited to economical/professional benefits but may also include other types of personal rewards (Panagopoulos and Karabarbounis 2020; Panagopoulos 2021). It is not unusual for important findings such as those reported above to be concealed or neglected in many publications, while their consideration is necessary for further developments.

At the same time, the massive deployment of the 5G MT/WC system in order to achieve ever increasing data transmission rates and the so-called Internet of Things (IoT) is well underway despite serious concerns expressed by many expert scientists who have asked for a moratorium in 5G deployment (Hardell and Nyberg 2020), as implied by the Precautionary Principle (Harremoes 2013; Read and O'Riordan 2017; Frank 2021). Indeed, the deployment of 5G will require a huge increase in the number of base antennas, combined with potential increases in transmission power/intensity, and thousands of satellites in the atmosphere to complement the base antennas. Moreover, the increased amount of variable data transmitted by this new WC EMR type make it even more variable in intensity, waveform, frequency, etc., with inclusion of ever more variable ELF pulsations than previous types of MT/WC EMFs (Rappaport et al. 2013; Dahlman et al. 2018). Thus, 5G is expected to significantly increase public exposure and consequent health problems (Panagopoulos 2019; Hardell and Nyberg 2020; Kostoff et al. 2020; Levitt et al. 2021).

Strangely, in 2020, the ICNIRP increased the general public exposure limit for WC EMFs (2–6 GHz) averaged over 6 minutes (min) from 1000 to 4000 μW/cm^2 (from 1 to 4 mW/cm^2) instead of decreasing it (ICNIRP 1998; 2020). Also strange were the technical reports and papers referring to the characteristics of 5G that do not provide any information on the ULF/ELF/VLF components of this new WC EMF type, as if their authors are not aware of their existence (EPRS 2020; 2021;

Karipidis et al. 2021). As already mentioned, carrying out studies involving WC EMF exposures without searching the low-frequency components and attributing any observed effects to the RF/MW carrier can be very misleading. Similarly, reviewing and evaluating other studies by looking only at the RF/MW part of their EMF exposures and ignoring the low-frequency part or not examining whether the exposures are from real-life WC devices/antennas or simulated signals with fixed parameters and, thus, significantly less bioactive, as in EPRS (2020; 2021) (EPRS: European Parliamentary Research Service) and Karipidis et al. (2021), is a flawed methodology. Thus, not only are WC EMFs dangerous to life, but the evaluation of their risks by certain reviews and organizations is flawed as well. In view of the fact that the ULF/ELF/VLF EMFs are actually the most bioactive, the low frequency (ULF/ELF/VLF) pulsations of the most recent generations of WC signals such as the 4G and 5G should be in the forefront of bioelectromagnetic research in order to allow the correct evaluation of their risks.

Because of the described confusion and misinformation, many people, especially among the general public, make careless use of WC devices, utilizing cordless domestic phones and Wi-Fi at homes and workplaces for convenience instead of using wired connections and attaching the mobile phones on their heads/bodies, subjecting themselves day and night to simultaneous telephone and Wi-Fi/Bluetooth EMF emissions from their "smart" devices. Unfortunately, they also give such devices in the hands of young children or even expose their embryos during pregnancy. So far, the authorities do nothing to educate them or protect them.

When, in many cases, people realize they have become hypersensitive to man-made EMFs, their efforts to restrict unbearable symptoms, especially from WC antennas, usually lead to risky solutions, such as metal shielding in their houses and even in their clothes. Any EMF-shielding attenuates not only the detrimental anthropogenic EMFs but also the natural and absolutely vital Schumann electromagnetic resonances, which actually attune our brain activity (Persinger 1974; 2014; Wever 1979; Cherry 2002; 2003; Panagopoulos and Chrousos 2019). Therefore, such solutions should be considered only when other ways of protection are not possible, and should be applied cautiously (after careful EMF measurements) and partially (e.g., only on certain wall(s) of a house), possibly in combination with earthing, and/or scientifically tested "Schumann generators" emitting very weak signals that mimic as closely as possible the Schumann oscillations (Panagopoulos and Chrousos 2019).

It seems that humanity and science are coming to realize that the price for the comfort provided by technology and the convenience in sharing information may be compromised health, wellbeing, and natural environment, when technology is not carefully designed to respect these values and health authorities do not set safe limits.

Another particularly worrying phenomenon is research on nanobiotechnology – magnetogenetics carried out during the past 10 years. Such research is crossing sensitive boundaries of bioethics by trying to control the cellular processes via magnetic nanoparticles injected in cells and manipulated by external electromagnetic signals (Monzel et al. 2017; He et al. 2021). Such methods can not only have unpredictable, adverse effects on the cell/organism, granted that such nanoparticles are unnatural and foreign to the cells, and are, thus, dangerous for many reasons and probably toxic, but can also violate the privacy and freedom of a treated individual, who could then be monitored and manipulated remotely by electromagnetic signals. It is questionable how such research is considered acceptable in the scientific community and compatible with bioethical principles.

This book on the Biological and Health Effects of WC EMFs includes contributions from top international experts on the various areas of this important subject and is published to increase scientific knowledge, awareness, and debate that would benefit science, public health, and the environment. Expert scientists were invited to submit specific chapters on the physics, biology, pathology, epidemiology, and plausible biophysical and biochemical mechanisms of action of WC EMFs. The invitations were specific. The contributors were invited to write on topics related to their previous publications and expertise so that the book covers a minimum number of the most important topics.

Because both RF and ELF EMFs are contained in all WC EMFs, studies on both frequency bands are examined in the chapters. Thus, the book describes effects from most types of man-made EMF exposures. In all chapters, the terms "EMF" and "EMR" (for example WC EMFs or WC EMR) are used interchangeably with equivalent meaning, as EMR is produced by temporally varying EMFs, and man-made (polarized and coherent) EMR carries net EMFs as well (Panagopoulos et al. 2015a). Moreover, because all types of WC EMFs commonly combine MW carrier waves with ELF modulation, pulsation, and ULF random variability, their biological/health effects are very similar, and, thus, they are treated similarly in the chapters, emphasizing though that newer generations of WC/MT EMFs (3G/4G/5G) are increasingly more variable and, thus, increasingly more bioactive. The terms "cell phone" and "cell tower" used occasionally in the book refer to digital mobile phones and base station antennas respectively. Thus, they have the same meaning as "mobile phones" and "MT base station antennas" (used in most cases) since all existing MT/WC systems (2G, 3G, 4G, 5G) today are digital. Digital MT uses the so called "cellular system" according to which the space is divided into areas called "cells" with one base station in each "cell".

The chapters present cutting-edge knowledge on the effects of man-made EMFs on living systems and their mechanisms. It is evident that serious effects induced by man-made and especially WC EMFs, such as genetic damage, are well documented as resulting from OS. This explains other reported pathological conditions, such as infertility or cancer. It is also evident that a most plausible biophysical/biochemical mechanism for OS induction in the cells is the dysfunction of the VGICs in the cell membranes and that the low frequency (ELF/ULF/VLF) components (pulsation, modulation, etc.) of the WC EMFs play a major role. The chapters emphasize the need for setting much tighter exposure limits and recommend prudent avoidance of exposure to man-made and especially WC EMFs, a moratorium in 5G roll-out, and urgent application of the Precautionary Principle (Harremoes 2013; Read and O'Riordan 2017; Frank 2021). Moreover, the chapters underline the need for improvement and standardization of the experimental procedures, use of real-life EMFs, and better definition of the EMF exposures by measuring all their parameters, especially the low-frequency ones.

I thank all the distinguished scientists in this book for kindly accepting my invitation, for their high-quality contributions, and their collaboration during the editing process. Inviting the chapters, editing, and shaping this book was, for me, a unique experience and a great source of combined knowledge. I also thank Dr. G.L. Carlo for writing the Forward of the book, and Dr. G. Singh from CRC for his invitation and repeated reminders to submit a book proposal.

This book will have served its purpose if it contributes toward setting scientific research in this field on a better base, leaving behind conflicts of interest and misinformation; when evidence-based discussions on the consequences of WC EMFs and possible correlations between an EMF-polluted environment and viral and other diseases are unbiased and welcomed by scientists, concerned individuals, health authorities and governments; when suggestions on individual and public health protection, and the setting of biologically and epidemiologically based exposure limits are also welcomed.

Finally, this book will have served its purpose if it contributes toward a "*real and honest science*" as Dr. Neil J. Cherry (1946–2003) would say. A science that is applicable to life and works for the benefit of humanity, not for its destruction or enslavement. A science that increases awareness on the safety of our natural environment and our planet Earth, which is in great danger because of the uncontrolled expansion of human technology and the unrestricted use of the natural resources.

We are gifted to live on this beautiful planet. We should love and respect it and live in harmony with it without destroying it. We should not disturb its natural balance by destroying the forests, changing the weather, genetically modifying our food and the natural organisms, filling the sky with thousands of satellites, and polluting the atmosphere with chemicals and artificial polarized EMFs/EMR. Instead of trying to inhabit other planets unfriendly to life, we should rather protect our home Earth, which is unique in the known universe. The balance of our planet is very fragile, and so is our existence. We all share the same home and the same future. It is our duty to protect it.

Dr. Dimitris J. Panagopoulos (Editor)

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