Defining Wireless Communication (WC) Electromagnetic Fields (EMFs): A) Polarization Is a Principal Property of All Man-made EMFs. B) Modulation, Pulsation, and Variabil....

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1 Defining Wireless Communication (WC) Electromagnetic Fields (EMFs):

A. Polarization Is a Principal Property of All Man-made EMFs
B. Modulation, Pulsation, and Variability Are Inherent Parameters of WC EMFs
C. Most Man-made EMF Exposures Are Non-thermal
D. Measuring Incident EMFs Is More Relevant than Specific Absorption Rate (SAR)
E. All Man-made EMFs Emit Continuous Waves, Not Photons
F. Differences from Natural EMFs. Interaction with Matter

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CONTENTS

Keywords: electromagnetic fields, non-ionizing electromagnetic radiation, physical properties, extremely low frequency, radio frequency, non-thermal biological effects, health effects.

Abbreviations: AM: amplitude modulation. CDMA: Code Division Multiple Access. DECT: Digitally Enhanced Cordless Telecommunications. DTX: Discontinuous Transmission Mode. EEG: electro-encephalogram. EHS: electro-hypersensitivity. ELF: Extremely Low Frequency. EMF:

electromagnetic field. EMR: electromagnetic radiation. ESR: electron spin resonance. FDTD: Finite Difference Time Domain. FM: frequency modulation. GMSK: Gaussian Minimum Shift Keying modulation. GSM: Global System for Mobile Telecommunications. LF: Low Frequency. LTE: Long-Term Evolution. MT: mobile telephony. MW: Microwaves. NMR: nuclear magnetic resonance. NR: New Radio. OS: oxidative stress. PM: phase modulation. QED: quantum electrodynamics. QEM: quantum electromagnetism. RADAR: radio detection and ranging. RF: Radio Frequency. SAR: Specific Absorption Rate. SCN: supra-chiasmatic nucleus. SD: Standard Deviation. SES: seismic electric signals. TDMA: Time Division Multiple Access. ULF: Ultra Low Frequency. UMTS: Universal Mobile Telecommunications System. VGIC: voltage-gated ion channel. VLF: Very Low Frequency. WC: wireless communications. Wi-Fi: Wireless Fidelity. WLAN: Wireless Local Area Network. 1G/2G/3G/4G/5G: first/second/third/fourth/fifth generation of MT.

ABSTRACT

All types of man-made electromagnetic fields (EMFs) and corresponding non-ionizing electromagnetic radiation (EMR) produced by electric/electronic circuits and antennas – in contrast to natural EMFs/EMR – are totally polarized and coherent. Polarized/coherent EMFs/waves can produce constructive interference and amplify their intensities at certain locations. Moreover, they induce parallel/coherent forced oscillations of charged/polar molecules – especially mobile ions – in living cells/tissues, which can trigger biological effects. The most bioactive man-made EMFs are those employed in wireless communications (WC). They are usually referred to simply as Radio Frequency (RF) or Microwave (MW) EMFs/EMR because they emit carrier signals in the RF/MW band. Yet, WC EMFs contain emissions in the Extremely Low Frequency (ELF), Ultra Low Frequency (ULF), and Very Low Frequency (VLF) bands as well in the form of modulation, pulsing, and variability. This complexity and variability of WC EMFs, combined with polarization, is what makes them even more bioactive. Man-made EMFs (including WC) at environmentally existing intensities do not induce significant heating in living tissues. The Specific Absorption Rate (SAR) was introduced by health agencies as the principal metric for the bioactivity of RF/microwave EMFs. Estimation of SAR from tissue conductivity is inaccurate, and estimation from tissue specific heat is possible only for thermal effects. Thus, SAR is of little relevance, and EMF exposures should better be defined by their incident radiation/field intensity at the included frequency bands, exposure duration, and other field parameters. The present chapter also explains that man-made EMFs/EMR, in contrast to light and ionizing electromagnetic emissions, do not consist of photons but of continuous "classical" waves and, thus, do not obey Planck's formula connecting photon energy (ϵ) with frequency (ν), $\epsilon = h\,\nu$. Apart from polarization, man-made EMFs differ from natural EMFs in frequency bands and emission sources. Basic concepts of interaction with living tissue are discussed.

1.1 INTRODUCTION

To address the bioactivity of electromagnetic fields (EMFs) and corresponding electromagnetic radiation (EMR) emitted by wireless communication (WC) devices/antennas, we must first know their physical properties. Applying various types of EMFs in biological experiments without good knowledge of their physical properties/parameters, or without good knowledge of the exposed biological model, will most likely lead to misinterpreted effects and misleading conclusions. Thus, the aim of this chapter is to define WC EMFs, the most complex type of man-made EMFs, by analyzing and describing their various physical parameters. This may provide a basis for future studies on the biological/health effects of WC EMFs.

Among the most important parameters of EMFs, in general, are frequency bands and corresponding intensities, polarization, waveform of the emitted waves/signals, and modulation/variability with a general meaning, which may include pulsations and different types of signal variability.

Apart from the field characteristics, the exposure duration is an additional important parameter for the induced effects (Panagopoulos 2011; 2017; 2019a).

The whole part of the electromagnetic spectrum from 0 Hz (static electric and magnetic fields) up to the low limit of infrared (approximately (~) 300 GHz = 3×10^{11} Hz) is, today, mainly occupied by anthropogenic/technical/artificial/man-made EMFs. They are produced by electric/electronic circuits and antennas of human technology. Applied voltages on those circuits force all free electrons in the metallic conductors to move back and forth in phase (coherently). As a basic principle of electromagnetism summarized in the Maxwell equations, EMR is produced when electric charges are accelerating (Tesla 1905; Alonso and Finn 1967; Reitz and Milford 1967; Alexopoulos 1973; Jackson 1975; Panagopoulos 2013). In this case, we have a continuous coherent acceleration (and deceleration) of free electrons. Due to the fixed position, geometry, and orientation of the circuits/antennas, all artificial (man-made) electromagnetic emissions are totally polarized, meaning their electric and magnetic fields oscillate on single planes (while being perpendicular to each other). This makes them particularly bioactive as discussed in Section 1.2 (and originally in Panagopoulos et al. 2015a; Panagopoulos 2017).

The velocity of any electromagnetic wave is the velocity of light c, as light consists of electromagnetic wave-packets called photons. In the vacuum or in the air, $c \approx 3 \times 10^8$ m/s, as measured experimentally by Heinrich Hertz in 1888. This represents an upper limit for all known velocities (Alonso and Finn 1967; Jackson 1975; Panagopoulos 2013). The velocity of EMR/light is an absolute, universal constant independent of any reference system (Beiser 1987).

The velocity of any wave in any medium is expressed as the product of its wavelength (λ) times its frequency (ν). Accordingly, the velocity of an electromagnetic wave is:

$$c = \lambda \cdot \nu \qquad [1.1]$$

The part of the man-made electromagnetic spectrum with the highest frequencies is called Radio Frequency (RF) band (300 kHz–300 GHz). RF EMFs are produced by electromagnetic oscillation circuits/antennas and are mainly used as carriers for transmitting information. Microwaves (MWs) are called the highest part of the RF band, with frequencies (300 MHz–300 GHz) higher than those which can be reflected by the ionosphere and transmitted over long distances around the Earth. This inability to travel long distances in the atmosphere is due to their smaller wavelengths, as described by the Rayleigh law (Eq. 1.2), which declares that the intensity of scattered EMR in any material medium is inversely proportional to λ^4 (λ the wavelength of EMR) or equivalently proportional to ν^4 (ν the frequency), when the dimensions of the scattering particles are smaller than the wavelength (Alexopoulos 1966; Jackson 1975) (which is the case for man-made EMFs):

$$J_{scat} \propto \frac{1}{\lambda^4} \quad or \quad J_{scat} \propto \nu^4 \qquad [1.2]$$

Since scattering increases with increasing frequencies, penetration into a material decreases. Because MWs are unable to travel long distances, unlike the electromagnetic waves of lower frequencies, and cannot be reflected by the ionosphere to go practically everywhere, their receiving and emitting antennas need to have optical contact between them or be close to each other, as with the antennas of mobile telephony (MT). This is why, while radio and television broadcasting antennas are restricted within antenna parks on top of mountains, WC antennas are excluded from this restriction. This, in turn, shows that health concerns are not taken into account by health authorities and national/international laws. The continuous demand for increasing the amount of transmitted information by MW antennas leads to the continuous increase in the MW frequencies, and the consequent approximation toward the low limit of infrared (Liolioussis 1979; 1997; 2009; Panagopoulos 2017).

In all information-carrying electromagnetic waves there is an RF/MW frequency carrier wave and a modulation field/wave which is, in most cases, of Extremely Low Frequency (ELF) (3–3000 Hz) (mostly) or Very Low Frequency (VLF) (3–30 kHz) and includes the information to be transmitted by the carrier. The frequency and the amplitude of the modulation field/signal vary continuously, depending on the varying information this signal includes (speech, text, images, etc.). In older analog radio, television broadcasting signals, or first-generation (1G) mobile phone signals, the RF carrier was a continuous-wave amplitude modulated (AM), or frequency modulated (FM), or phase modulated (PM) by the ELF/VLF information signal. In modern digital WC, the emissions are in the form of "on/off" pulses, repeated with a namely standard frequency in the ELF/VLF band which actually varies as well. The pulses are most usually rectangular with fast rise and fall times and variable intensity. Each rectangular pulse is an "envelope" containing the RF carrier wave/signal modulated by the information signal (ELF/VLF). Radio detection and ranging (RADAR) emissions/signals are also pulsed for energy-saving reasons with "on/off" pulses, but in this case, the pulses are invariable (Puranen and Jokela 1996). The pulses are, in most cases, emitted at rates of tens, or hundreds, or thousands per second (ELF). In WC signals, the pulses are used not only for energy saving but also mainly for increasing the number of users communicating each moment with the same antenna and exchanging different types of information (speech, text, images, etc.). This is called "multiplexing". The variable pulsations in combination with the modulation and other factors create an additional variability of the final signal, which is usually in the Ultra Low Frequency (ULF) (0–3 Hz) band (Alonso and Finn 1967; Alexopoulos 1973; Jackson 1975; Schwartz 1990; Holma and Toskala 2004; Panagopoulos 2011; 2013; 2017; 2019a; Pirard and Vatovez).

A single WC device (e.g., mobile or cordless phone) emits pulses for a single user. Groups of thousands of such pulses emitted by MT base antennas, or Wireless Local Area Network (WLAN) also called Wireless Fidelity (Wi-Fi) routers for Internet access, carry the transmitted information of many users simultaneously assigning a single pulse-type, or pulse-timing, or code to each user, differing slightly in position/frequency/code from other pulse types of other users. When a "smart" mobile phone, with its multiple antennas, is simultaneously connected to telephony, Internet, or/and other devices (e.g., printers) via local ("Bluetooth") connections, different types of pulses from different antennas with different carrier/modulation/pulsing frequencies and intensities, etc., accommodate each connection, making the overall field/signal extremely complicated and unpredictably varying each moment.

Thus, WC EMF emissions, except for the RF/MW carrier signal, always include ELF/ULF (0–3000 Hz) emissions in the form of modulation, pulsing, and random variability. The intensity, frequency, and shape of these ELF/ULF components are not invariable/predictable as in non-information-carrying RF emissions (e.g., from radars or MW ovens) but unpredictably varying each moment (Pedersen 1997; Hyland 2000; 2008; Zwamborn et al. 2003; Holma and Toskala 2004; Curwen and Whalley 2008; Pirard and Vatovez). This high complexity and variability of the WC EMFs makes them significantly more bioactive than other types of man-made EMFs, as living organisms cannot adapt to unpredictably varying stressors (Panagopoulos 2019a).

A careful examination of the so-called "RF" EMF exposures employed in the vast majority of experimental EMF bioeffects studies would reveal that these were not purely RF but complex EMFs like those employed in WC and, in most cases, simulated MT EMFs, or real-life MT EMFs from commercially available mobile/cordless phones, combining RF and ELF components (Azanza et al. 2002; Panagopoulos et al. 2004; 2007a; 2007b; 2015b; 2021; Belyaev 2005; Behari 2010; Yakymenko et al. 2016; Wust et al. 2021; Bertagna et al. 2021). The combined frequency bands and variability in WC EMFs are discussed in Section 1.3 of this chapter (and originally in Panagopoulos et al. 2015b; Panagopoulos 2017; 2019a).

Living organisms have developed effective protection mechanisms against natural stress of different types (heat, cold, starvation, natural chemical toxicity, solar ultraviolet radiation, natural radioactivity, etc.). Moreover, it seems they can adapt to stressors which are predictable (invariable).

They are adapted to the presence of the significantly/locally polarized static terrestrial EMFs (geoelectric and geomagnetic field), but only when these fields are kept relatively constant despite their normal small ELF variations. When such fields vary by ~ 20% of their normal average intensities during magnetic storms taking place on Earth every several years due to increased solar activity, adverse health effects initiate in humans/animals (Presman 1977; Dubrov 1978; Panagopoulos 2013). Thus, the combination of polarization and significant ELF variability of EMF exposure is a natural trigger of biological effects (Panagopoulos 2019a). This bioactive combination in maximum levels is the case in WC EMFs. In the present chapter, we shall examine this systematically.

Man-made EMFs and corresponding non-ionizing EMR are actually very different and much more adversely bioactive than natural EMFs. Natural EMFs on Earth (such as natural light, the geoelectric and geomagnetic fields, and the atmospheric “Schumann” oscillations) are vital, as all living creatures have evolved in their presence, and no life would exist without them. The 24-hour (h) day–night periodicity of natural light attunes the central nervous system of all animals on Earth. In mammals, this is accomplished via the supra-chiasmatic nucleus (SCN) a group of neurons above the optic chiasm (Panagopoulos 2013). Atmospheric electromagnetic ELF oscillations created by lightning discharges, called Schumann resonances, play a most vital role in attuning the brain’s electrical activity in all animals. It is no chance that the basic frequency of the alpha rhythms of animal/human brain oscillations (7.83 Hz) coincides with the basic frequency of the atmospheric Schumann resonances (Berger 1929; Schumann 1952; Wever 1974; 1979; Panagopoulos and Balmori 2017; Panagopoulos and Chrousos 2019). Similar vital action is exerted by the natural EMFs in all living creatures (trees, plants, etc.) (Presman 1977; Dubrov 1978; Alberts et al. 1994).

By contrast, man-made EMFs have an adverse action on living organisms, except for specific therapeutic applications when they are specifically designed to amplify/restore endogenous electric currents in cells and tissues or simulate natural exogenous EMFs such as the Schumann resonances (Wever 1974; 1979; Nuccitelli 1992; 2003; Panagopoulos 2013). Indeed, externally applied static electric fields of similar intensities and directions with endogenous fields controlling, e.g., cell proliferation, have been found to stimulate mammalian and amphibian nerve regeneration, nerve sprouting at wounds, wound healing, or spinal cord injury healing (Borgens 1988; Nuccitelli 2003; Wang and Zhao 2010). Accordingly, pulsing ELF EMFs have been found to accelerate bone regeneration and bone fracture healing in mammals (Bassett et al. 1964; Brighton et al. 1979; 1987; 1989).

Apart from the specific therapeutic effects when weak static or ELF technical EMFs mimic natural/endogenous EMFs, thousands of studies during the past five decades have indicated a variety of adverse biological effects induced in a variety of organisms/cell types by exposure to man-made EMFs, especially ELF and complex “RF” (including ELF modulation/pulsation/variability). The recorded biological and health effects range from alterations in the synthesis rates of critical biomolecules such as proteins, RNA, DNA, etc., alterations in enzymatic activity, in intracellular ionic concentrations (Ca^{+2}, Na^{+}, K^{+}, Cl^{-}, etc.), or in cell proliferation rates, to oxidative stress (OS), DNA and protein damage, chromosome damage, cell death, infertility, electro-hypersensitivity (EHS), and cancer (Marino and Becker 1977; Wertheimer and Leeper 1979; Adey 1981; 1993; Goodman et al. 1995; Santini et al. 2005; Diem et al. 2005; Hardell et al. 2007; 2013; Phillips et al. 2009; Khurana et al. 2009; Blackman 2009; Johansson 2009; De Iuliis et al. 2009; Yakymenko et al. 2011; 2016; 2018; Houston et al. 2016; Panagopoulos 2011; 2017; 2019a; 2019b; 2020; Panagopoulos et al. 2007a; 2007b; 2010; 2013a; Chavdoula et al. 2010; Miller et al. 2018; 2019; Belpomme and Irigaray 2020). All these reported effects are not accompanied by heating of the exposed biological tissues.

Under the weight of this accumulating evidence, especially on genotoxic effects and carcinogenicity, the International Agency for Research on Cancer (IARC), which is part of the World Health Organization (WHO), has classified both ELF and RF EMFs as possibly carcinogenic to humans (Group 2B) (IARC 2002; 2013). Recent carcinogenicity updates advocate that WC EMFs containing both RF and ELF should be categorized as “probably carcinogenic” or “carcinogenic” (Miller et al. 2018; NTP 2018; Falcioni et al. 2018; Hardell and Nyberg 2020). The field/radiation intensities and exposure durations in the majority of published man-made EMF studies are significantly smaller than those of exposures to natural EMFs in the terrestrial environment, even though in different frequency bands (Panagopoulos 2015a; 2019a).

Solar EMR intensity incident upon a human body ranges normally between 8 and 24 mW/cm^2 (depending on seasons, atmospheric conditions, geographical location, etc.) (Roller and Goldman 1968; Parsons 1993; Panagopoulos 2017), while corresponding intensity from a digital second or third, or fourth generation (2G/3G/4G) mobile phone handset upon a human head (even in contact) during a usual phone-call in "talk" mode is normally less than 0.2 mW/cm^2 (Table 1.1). Similarly, infrared radiation, from every human body at normal temperature has significantly greater incident intensities and exposure durations on any human than most artificial EMF sources (Presman 1977; Dubrov 1978; Gulyaev et al. 1995). How, then, can natural EMFs be beneficial, while man-made EMFs are detrimental?

The unique property that makes human-made EMFs so much more adversely bioactive compared to natural EMFs and natural light is polarization (combined with coherence) (Panagopoulos et al. 2015a; Panagopoulos 2017). Polarized and coherent EMFs/EMR are specifically bioactive because they can induce parallel and coherent forced oscillations of electrically charged and polar molecules which constitute the vast majority of molecules in living tissues. Moreover, they can interfere with each other and amplify their intensities at certain locations, (Panagopoulos et al. 2015a). The combination of polarization/coherence and the extreme complexity/variability of the WC EMF exposures is what makes them extremely bioactive and, thus, dangerous to all living organisms (Panagopoulos 2019a). Before the past ~120 years (and intensely the past ~25 years), living organisms had never been exposed to anything similar to man-made polarized/coherent and oscillating/pulsing EMFs and, thus, have not developed any defense mechanisms against this new unphysical type of stress.

Modulated (especially in amplitude) or pulsed RF EMFs are repeatedly found to be more bioactive than non-modulated or non-pulsing fields of the same carrier frequency and of the same average intensity (Bawin et al. 1975; 1978; Blackman et al. 1980; 1982; Lin-Liu and Adey 1982; Byus et al. 1984; 1988; Frei et al. 1988; Somosy et al. 1991; Veyret et al. 1991; Bolshakov and Alekseev 1992; Litovitz et al. 1993; Thuroczy et al. 1994; Goodman et al. 1995; Penafiel et al. 1997; Huber et al. 2002; Höytö et al. 2008; Hinrikus et al. 2008; Franzellitti et al. 2010; Campisi et al. 2010; Mohammed et al. 2013). Frei et al. (1988) found that a 2.8 GHz RF EMF pulsed at 500 Hz was significantly more effective in increasing heart rate in rats than the corresponding non-pulsed RF 2.8 GHz EMF with the same average intensity and exposure duration. Huber et al. (2002) and Mohammed et al. (2013) found that exposure to 900 MHz RF EMF pulse-modulated with various ELF pulsations induced changes in the human and rat electro-encephalograms (EEG), while the corresponding non-pulsed EMF (same RF frequency without any pulsation) with the same exposure duration did not. Similarly, Franzellitti et al. (2010) found that a 1.8 GHz RF signal amplitude-modulated by ELF pulsations induced DNA damage in cultured human trophoblast cells, while the corresponding non-modulated signal with the same exposure duration was ineffective. In all the above cases, the reported effects were not accompanied by any significant tissue heating. This significant evidence indicates that the non-thermal effects of WC EMFs on living organisms are mainly due to the included ELFs.

Moreover, ELF EMFs alone are found independently to be bioactive, as are RF EMFs modulated or pulsed by ELFs (Bawin and Adey 1976; Blackman et al. 1982; Walleczek 1992; Ma et al. 1993; Goodman et al. 1995; Azanza et al. 2002; Ivancsits et al. 2002; 2003; Santini et al. 2005; Panagopoulos et al. 2013a). Bawin and Adey (1976) found that the ELF sinusoidal signals previously used to modulate an RF carrier EMF (Bawin et al. 1975; 1978), induced alone (without the RF carrier) alterations in Ca^{2+} concentration in chicken and cat brain cells as did the modulated RF EMF, while the RF carrier alone (non-modulated) was ineffective. Azanza et al. (2002) found that the ELF pulsations employed in 2G MT at 8.3 and 217 Hz could, by themselves (without the carrier RF signal), induce changes in the spontaneous bioelectric activity of neurons. Again, in all cases, the described effects were non-thermal.

Thus, in the absence of the ELF/ULF components, the effects usually disappear, as several studies have shown (Bawin et al. 1975; 1978; Blackman et al. 1980; 1982; Goodman et al. 1995; Huber et al. 2002; Belyaev 2005; Franzellitti et al. 2010; Mohammed et al. 2013; Panagopoulos 2019a), and purely RF EMFs, without ELF pulsing or modulation, usually do not induce the above reported non-thermal effects. By contrast, ELF EMFs alone induce non-thermal effects, alike the RF EMFs modulated or pulsed by ELFs (Bawin and Adey 1976; Blackman et al. 1982; Walleczek 1992; Goodman et al. 1995; Ivancsits et al. 2002; 2003; Santini et al. 2005; Panagopoulos et al. 2013a). The fact that a variety of biological systems/living tissues respond differently to pure RF exposures than to those including ELF modulation/pulsation/variability shows that living tissue responds specifically to the ELF components of a complex RF signal containing both RF and ELF components. This is of great significance. Whether living tissue has the ability to "demodulate" the ELF components from the complex signal (Blackman et al. 1982) or these components are already independent within the signal is not the case.

The above experimental findings showing the unique ability of ELF EMFs to induce bioeffects are well explained by the "ion forced-oscillation mechanism" for irregular gating of electrosensitive ion channels in cell membranes which predicts that pulsing EMFs are more bioactive than non-pulsing EMFs of the same other parameters and that the biological activity of any specific type of EMF is inversely proportional to its frequency and proportional to its intensity (Panagopoulos et al. 2000; 2002; 2015a; 2020; 2021).

As reported already, the above-described effects induced only in the presence of ELF EMFs are non-thermal. The only EMF exposures that cause heating (thermal effects) in living tissues are those to high frequency (of the order of GHz or higher) and high intensity/power EMR ($\geq$0.1 mW/cm^2), in other words to intense RF/MW EMFs and, in this case, the presence of ELF components is not necessary. This is a well-known effect called "microwave heating" (Metaxas 1991; Walleczek 1992; Creasey and Goldberg 2001; Belyaev 2005; Panagopoulos 2011; 2017; Wust et al. 2021). Therefore, polarized ELF EMFs at environmental intensities induce non-thermal adverse effects in living organisms, while polarized intense RF EMFs induce only heating (just like the infrared or visible light) in both inanimate and living matter. Thermal and non-thermal effects and related mechanisms are analyzed in Section 1.4.

In addition, real-life, highly varying WC EMFs have been found to be more bioactive than corresponding simulated WC EMFs with invariable parameters produced by generators or "test" phones (Panagopoulos et al. 2015b; Panagopoulos 2017; 2019a; Leach et al. 2018; Kostoff et al. 2020). This shows that unpredictable, intense variability of an EMF exposure is an additional bioactive factor.

The International Commission for Non-Ionizing Radiation Protection (ICNIRP) is a private, non-governmental organization (NGO) that sets EMF exposure standards and claims that the only biological effects induced by EMFs are those due to tissue heating (thermal effects) in the case of RF EMFs, and denies any non-thermal effects (ICNIRP 1998; 2020; Hardell and Carlberg 2021). Facts show that only RF exposures with frequencies at the GHz range or higher and intensities greater than 0.1 mW/cm^2 may induce tissue heating, usually of the order of 0.1–0.3°C, and, thus, the vast majority of EMF exposures at environmentally existing intensities, mainly due to ELF EMFs alone or combined with RF, are non-thermal (Panagopoulos et al. 2013b). Yet, the thermal effects are expected to become more significant with the higher frequencies of 5G (up to 100 GHz) (Neufeld and Kuster 2018). Even though ICNIRP accepts (only) the thermal effects of RF EMFs, it has recently increased the average 6-minute (min) exposure limit for 2–6 GHz from 1 mW/cm^2 to 4 mW/cm^2 (ICNIRP 2020). Thus, not even thermal effects are prevented by the ICNIRP limits anymore.

The IARC (2002; 2013) accepts the non-thermal biological effects recorded by thousands of experimental studies at different frequencies and intensities; however, like the ICNIRP, it does not recognize that what are called simply "RF" EMFs are actually, in most cases, complex WC EMFs, including both RF and ELF/ULF components. Moreover, the IARC (2013) adopts metrics pertaining exclusively to thermal effects such as the Specific Absorption Rate (SAR) and suggests that experimental studies should be performed with simulated MT EMFs with invariable field parameters emitted by generators, while real-life WC (including MT) EMFs are highly variable. The result is that about 50% of the studies performed with simulated signals find "no effects", while more than 95% of the studies using real-life exposures from mobile phones, cordless domestic phones, Wi-Fi routers, etc., find effects (Panagopoulos et al. 2015b; Panagopoulos 2017; 2019a; Leach et al. 2018; Kostoff et al. 2020). Thus, even though the IARC accepts the non-thermal effects, it does not recognize the combined RF–ELF character of the complex WC EMFs, evaluating them simply as "RF", adopts a thermal metric for their evaluation, and overlooks the fact that it is the intense variability that makes real-life WC EMF exposures so bioactive, accepting only studies employing simulated WC exposures with no signal variability in order for the exposures to be "determined" (accurately measured). Thus, both the ICNIRP and the IARC bear great responsibility for the continuing confusion and underestimation of the health risks of WC EMFs by scientists, physicians, health authorities, and the general population.

Health agencies introduced SAR as a principal metric for the bioactivity of RF/MW EMFs/non-ionizing radiation. It expresses the rate of energy absorption (power) per unit of mass of exposed living tissue (in W/kg) in accordance with the rate of absorbed dose in the case of exposure to ionizing radiation (NCRP 1986; Coggle 1983).

But there is a significant difference between RF EMFs/EMR and ionizing electromagnetic radiation regarding their biological/health effects: The biological effects of ionizing EMR (from vacuum ultraviolet to gamma rays with frequencies ranging from ~3×10^{16} to ~3×10^{22} Hz) depend largely on the high energies of ionizing photons absorbed completely by electrons or nuclei. Such photons are capable of causing direct ionization by breaking chemical bonds, expelling electrons from atoms, or even breaking nuclei in the case of gamma rays, etc. The amounts of energy deposited in exposed single molecules, even in the softest ionizing case of vacuum ultraviolet (>10 eV $\approx 1.6 \times 10^{-18}$ J), are great enough to ionize them. By contrast, the corresponding amounts of absorbed energy by single molecules (mobile ions), in the case of man-made EMF exposures, are millions of times smaller than the average thermal energy of the same molecules at human body temperature ($kT \approx 4.3 \times 10^{-21}$ J) (as analyzed in Section 1.4) and, thus, are billions of times smaller than in the softest case of ionizing exposures. In fact, in most cases, ionizing exposures are of several orders of magnitude greater photonic energy than 10 eV (vacuum ultraviolet), as x-rays have energies around 1–100 keV and gamma rays100 keV–100 MeV (Alexopoulos 1963; Gautreau and Savin 1978; Coggle 1983; Prasad 1995). Thus, evaluating man-made EMF exposures by metrics similar to those used for ionizing radiations is neither very relevant nor useful.

As shown in Section 1.5, SAR actually accounts only for thermal effects (heating), while the effects of man-made EMFs (frequencies lower than infrared) do not usually induce any significant (or even measurable) heating in living tissues.

Moreover, there are other parameters of an EMF exposure more important for the induced biological effects, such as polarization, the field/radiation intensity at the various included frequencies (carrier, pulsing, etc.), the variability of the field, the duration, intermittence, and timing of the exposure (Diem et al. 2005; Belyaev 2005; Chavdoula et al. 2010; Panagopoulos and Margaritis 2010a; Panagopoulos et al. 2007a; 2007b; 2010; 2015a; 2015b; Panagopoulos 2017; 2019a). These important parameters are not included in the absorbed power (SAR).

Today, there are hundreds of studies that correspond specific biological effects to specific incident radiation/field intensities at different frequency bands which can be measured much more easily and reliably than SAR (see Panagopoulos et al. 2010, and reviews Adey 1981; 1993; Goodman et al. 1995; Santini et al. 2005; Phillips et al. 2009; Panagopoulos and Margaritis 2009; Manna and Gosh 2016; Leach et al. 2018; Panagopoulos 2019a). Thus, we can predict the expected effect by knowing the incident radiation/field intensity plus the other parameters of the field/exposure (Panagopoulos et al. 2013b).

Another important parameter for the definition of a particular type of EMF/EMR and consequently, for its predicted bioactivity, is whether its emitted waves are continuous waves as those described by classical electromagnetism, or discrete wave-packets (photons). It is well documented that natural light (infrared, visible, ultraviolet), x-rays, and gamma radiation are emitted in the form of discrete wave-packets (or "particles" of light) called quanta or photons, each having a discrete frequency, phase, and polarization, and its energy (∈) is given by the Planck formula:

$$\in = h\nu \quad \text{or} \quad \in = \hbar\omega \qquad [1.3]$$

($h = 6.625 \times 10^{-34}$ J·s is called Planck's constant, $\hbar = h/2\pi$, ν is the frequency of the wave-packet, and $\omega = 2\pi\nu$ is the circular frequency).

An unphysical postulate of modern quantum physics called quantum electromagnetism (QEM) or quantum electrodynamics (QED) is that not only light, x-, and gamma radiation, but also every form of EMF/EMR is quantized, i.e., consists of quanta (photons) (Panagopoulos 2015; 2018). This was established around 1925–1930 when the founders of QED/QEM (Heisenberg, Dirac, Born, and others) mathematically transformed the energy of the EMF into a Fourier series of discrete terms which were arbitrarily attributed to photons. This was not dictated or even implied by experimental facts and was based on the simplistic hypothesis that any EMF/EMR is a periodic function of time (Panagopoulos 2018).

It was already shown by Planck, Einstein, Bohr, and others that natural light is quantized, i.e., consists of photons, and the physics community considered that any form of EMF/EMR should, therefore, consist of photons. That was a flawed and arbitrary extrapolation. Technical (man-made EMFs) were still very new at that time and not explored in depth with regard to their differences from natural light or other types of natural EMR, which had not been discovered yet, such as the Schumann oscillations or the cosmic "microwaves". Possibly, the founders of QEM/QED did not mean that their "quantization" applies to every form of EMF/EMR that was to be discovered or produced in the future. But the physics community of that time and during the next decades (Feynman 1950), apart from a few exceptions, took for granted that this was the case.

The "official" opinion is that "electromagnetic signals are always composed of photons, although in the circuit domain those signals are carried as voltages and currents on wires, and the discreteness of the photon's energy is usually not evident" (Schuster et al. 2007). While they take for granted the existence of photons in man-made EMFs/EMR and especially in the RF/MW band, they admit that single MW photons have not been detected: "Verifying the single-photon output is a substantial challenge in on-chip microwave experiments. The simplest approach, that of looking for a photon each time one is created, is not currently possible; no detectors can yet resolve single MW photon events in a single shot" (Houck et al. 2007). While the alleged evidence for the existence of RF/MW photons is highly questionable, there is absolutely no evidence of photons in lower frequency bands such as VLF/LF (3–300 kHz), or ELF/ULF (0–3000 Hz). Several quantum physicists have objected to QEM/QED (Jaynes 1966; 1978; 1980; Lamb and Scully 1969; Hunter and Wadlinger 1987; Vistnes and Gjoetterud 2001; Roychoudhuri et al. 2008; Roychoudhuri 2014). Vistnes and Gjoetterud (2001) have argued that considering ELF EMFs as consisting of photons is highly misleading.

The following facts contradict the existence of photons for frequencies below infrared ($0–3 \times 10^{11}$ Hz): 1) There is no experimental proof nor explanation based on physical phenomena for the existence of such photons in environmental conditions; 2) there are no discrete lines in ELF, VLF, LF, RF antennae spectra; 3) all interactions of man-made EMFs (from ELF to RF) with matter (both biological and inanimate) are very successfully studied by classical electromagnetism; and 4) the "quantization" of the EMF was a mathematical transformation based on simplistic hypotheses.

Today, those who claim that man-made EMFs are harmless to life argue that their frequencies and, consequently, their "photon energies" are smaller than those of visible light (according to Eq. 1.3) and, thus, are unable to induce any adverse effect in living organisms (Valberg et al. 1997; Sheppard et al. 2008; Levitt et al. 2021). We shall show that this argument is flawed because: a) man-made EMFs/EMR produced by electric/electronic circuits/antennas consist of continuous/uninterrupted waves like those described by classical electromagnetism, not photons (Section 1.6);

b) man-made EMFs are totally polarized and coherent, while natural light is not (Section 1.2); c) most biological/health effects of man-made (including WC) EMFs are not accompanied by any significant heating of the exposed living tissues, in contrast to those of natural light, and are due to ELF, not to the RF or the even higher frequencies of natural light (Section 1.4); and, most importantly, d) thousands of experimental studies have already shown a plethora of effects induced by man-made EMFs which cannot be denied.

The IARC (2013) has correctly avoided mentioning the alleged "photonic" nature of man-made EMFs/EMR, noting that "the photon energy is generally referred to in the x-ray and gamma-ray regions, and also to some extent in the ultraviolet range, because the particle-like properties of the EMFs become more obvious in these spectral regions" and points out that RF EMFs are described by Maxwell's equations (classical electromagnetism) (pages 37–38).

The important differences among natural and man-made EMFs/EMR in the non-ionizing band (from 0 Hz up to ultraviolet) are summarized in Section 1.7. The differences are specified in polarization, frequency bands, and emission sources (bound versus unbound charged microparticles). The basic concepts of interaction of natural and man-made EMFs/EMR with matter, such as excitation/de-excitation and forced oscillation of charged/polar particles, are also discussed in the same section.

In Sections 1.2–1.7, the above briefly described important issues regarding the definition of man-made EMFs, and particularly WC EMFs, are specifically examined. As already noted, the purpose of this chapter is to increase knowledge, awareness, and debate among scientists on the complexity of these new types of man-made EMFs which have already overflowed the planet, exposing every living creature for the first time within the billions of years of biological evolution. Understanding the properties and complexity of these man-made EMFs and clarifying confusing diverse information is the first necessary step to understanding their impacts on life.

1.2 POLARIZATION IS A PRINCIPAL PROPERTY OF ALL MAN-MADE EMFs

1.2.1 Defining Polarization. Why Man-made Polarized EMFs Are More Adversely Bioactive than Natural Non-polarized EMFs

Here, we shall explain theoretically that the increased adverse biological action of man-made EMFs is, first of all, due to polarization, a property that only partially and occasionally exists in natural EMFs (Panagopoulos et al. 2015a; Panagopoulos 2017). Man-made EMFs are produced by electric/electronic circuits, and the corresponding EMR is emitted by the acceleration of free electrons forced to oscillate back and forth along the metallic conductors of such circuits. Because the electronic oscillations take place macroscopically in specific directions/orientations determined by the geometry/orientation of the circuit/antenna, the corresponding oscillating fields and generated waves oscillate on a single plane, and thus, they are totally polarized (in most cases linearly polarized) In contrast, natural electromagnetic emissions (cosmic microwaves/infrared, visible, ultraviolet, x-, and gamma radiation) produced by molecular/atomic/nuclear events are not polarized, and only in specific occasions may light be partially polarized. First, we must provide some definitions and equations on polarization, field intensity, wave intensity, and superposition/interference of EMFs/EMR, which will be necessary for understanding why polarized EMFs are so much more bioactive than non-polarized.

A field/wave is called linearly polarized when it oscillates on a single plane, which is called the "polarization plane". While the intensity of a non-polarized field at any point in space oscillates in every possible direction, the intensity of a linearly polarized field at any specific point oscillates on one line (Figure 1.1). Linearly polarized waves are also called "plane waves". A combination of linearly polarized fields/waves with certain phase differences among them can give circularly or elliptically polarized fields/waves. Specifically, superposition of two identical fields with a phase difference of 90° among them creates a circularly polarized field. Superposition of three identical fields with a phase difference of 120° among each two of them also creates a circularly polarized field. The same conditions with unequal amplitudes create elliptically polarized fields. Circularly and elliptically polarized 50–60 Hz sinusoidal alternating electric and magnetic fields produced by three-phase electric power transmission lines (120° phase difference among each two phases) are accused for association with cancer, while linearly polarized such fields produced in the lab are repeatedly found to induce DNA damage, cell death, infertility, alterations in DNA synthesis, and cell proliferation rates, and a variety of other adverse effects in experimental animals and cell cultures (Marino and Becker 1977; Wertheimer and Leeper 1979; Adey 1981; 1993; Schimmelpfeng and Dertinger 1993; Goodman et al. 1995; IARC 2002; Ivancsits et al. 2002; 2003; Santini et al. 2005; Phillips et al. 2009; Panagopoulos et al. 2013a).

Natural EMR/EMFs (atmospheric "Schumann" oscillations, cosmic MWs, infrared, visible light, ultraviolet, gamma rays) and several forms of artificially triggered natural electromagnetic emissions (such as from incandescent lamps, gas discharge lamps, x-rays, lasers, etc.) are not polarized, meaning that their electric and magnetic fields oscillate on any possible random plane while being perpendicular to each other. Light (infrared, visible, ultraviolet), x, and gamma rays are produced by great numbers of molecular, atomic, or nuclear transitions of random orientation and random phase difference among them (except for lasers, which are coherent). These transitions are excitations/de-excitations of molecules, atoms, or atomic nuclei. During each such transition, a single photon is emitted (Beiser 1987). Each photon (i.e., wave-packet) oscillates on a distinct random plane, and, therefore, it has a distinct different polarization. Moreover, the different photons are not produced simultaneously, but they have random phase differences among them (Panagopoulos et al. 2015a; Panagopoulos 2018). Schumann oscillations in the Earth's atmosphere are non-polarized stationary waves generated by atmospheric discharges (lightning) during thunderstorms that occur any moment on Earth. The above natural EMFs are oscillating and non-polarized.

The geoelectric and geomagnetic fields (with average intensities ~ 130 V/m and ~ 0.5 G = 0.05 mT, respectively) and the electric fields of cell membranes in all living organisms (~10^7 V/m) are locally polarized, accepting that their field lines are practically parallel among them at a certain location. These are examples of locally polarized natural EMFs. All three of them are basically static (invariable in their polarities and average intensities). There are also transient polarized signals associated with certain natural phenomena. The strongest lightning discharges from clouds to ground during thunderstorms can be considered as ~ 70% straight lines with a reasonable approximation, and thus, their emitted EMFs (called "sferics") can be considered as being ~ 70% polarized. Seismic electric signals (SES) emitted a few days or weeks prior to major earthquakes are weak, significantly polarized pulses. Both of these natural EMFs, due to their significantly polarized nature, can be sensed by sensitive animals/individuals (Panagopoulos and Balmori 2017; Panagopoulos et al. 2020), and this is probably a way for protection of the living organisms against intense natural phenomena developed during the biological evolution.

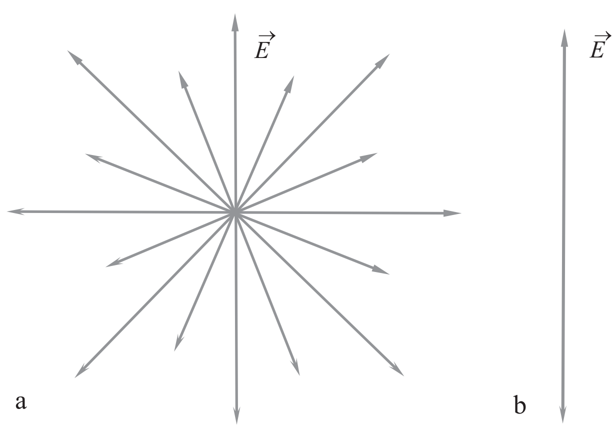

FIGURE 1.1 (a) Non-polarized field, (b) Linearly polarized field.

The effect of light interference discovered by Thomas Young in the early 1800s takes place among waves (photons) having identical polarization and frequency (Arago and Fresnel 1819; Panagopoulos 2015). In his experiments, natural light from a single source passes through two identical small slits at equal distances from the source which, in turn, become two identical coherent secondary sources, according to the Huygens principle, and the light from the two secondary sources forms standing luminous and dark parallel fringes on a screen behind the slits (Pohl 1960; Alonso and Finn 1967). As became clear from subsequent experiments in the following years, and summarized in the Arago-Fresnel experimental laws, only coherent polarized fields/waves of identical polarization and frequency are able to produce clear standing interference effects (fringes of maximum and minimum light intensity) (Arago and Fresnel 1819). [An explanation of how natural non-polarized and incoherent light in the Young experiments produces standing interference is given in Panagopoulos (2015) and is based on the fact that each single photon of natural light has a distinct polarization, frequency, and phase, though different than those of the other photons. Two parts of each single photon pass simultaneously through the two slits and then interfere with each other.] What is important, here, is that only polarized EMFs/EMR of the same polarization can produce constructive or destructive interference with each other, and amplify or cancel their intensities respectively, at the specific locations where two or more waves are superimposed on each other with the same or opposite phases. The ability of constructive or destructive interference is a unique property of polarized waves/fields with great significance in their bioactivity.

Apart from polarization, when the EMFs are in addition of the same frequency, the interference fringes are standing at certain locations (when the sources are also standing). This is called standing interference. When the polarization is fixed (e.g., vertically oriented antennas), but there are differences in frequency among the sources, the interference effects are not standing at fixed locations but, instead, change with time, creating instantaneous peaks at changing locations. Several oscillating EMFs of the same polarization, such as the fields from different antennas vertically oriented, may also produce transient constructive interference effects and instantly amplify the local field intensity at different locations. At such locations, any living organism can be instantly exposed to significantly higher intensities and become more vulnerable to the adverse action of these fields (Sangeetha et al. 2014; Panagopoulos et al. 2015a).

In addition, oscillating polarized (and coherent) EMFs/EMR (in contrast to non-polarized) have the ability to induce parallel and coherent forced oscillations on any charged/polar particles within a medium. In case the medium is biological tissue, the result is that all charged (bio)molecules will be forced to oscillate in parallel and in phase with the field. These parallel and coherent forced oscillations can trigger biological effects (Panagopoulos et al. 2000; 2002; 2015a; 2020; 2021).

Non-polarized EMR can become polarized when it passes through anisotropic media with specific molecular orientations, as are certain crystals. In fluids (gases and liquids), the molecules are randomly oriented and, macroscopically, are considered isotropic, inducing no polarization in the electromagnetic waves transmitted through them. Non-polarized and incoherent natural light can become partially polarized to a small degree after diffraction on atmospheric molecules or reflection on water, mirrors, metallic surfaces, etc. In contrast, a polarized beam cannot be unpolarized but may only be absorbed by a medium (Alonso and Finn 1967). Thus, living organisms, exposed to natural radiation throughout biological evolution, have been exposed to incoherent, partially polarized to a small degree light, under certain circumstances, but have never been exposed to totally polarized and coherent radiation, such as the EMR/EMFs of the human technology (Chen and Rao 1968; Cronin et al. 2006; Panagopoulos et al. 2015a).

1.2.2 Field Intensity and Radiation Intensity

Any harmonically oscillating physical quantity A propagating along a direction r with velocity u, is described by the classical harmonic plane wave equation:

$$A = A_o sin\left(\omega t - k_w r\right) \qquad [1.4]$$

where A_o is the amplitude (max value) of the oscillating quantity, r the distance of propagation in time t, k_w (=$2\pi/\lambda$) is the wave number (λ the wavelength), and $\omega = 2\pi\nu = k_w u$ is the circular frequency of the wave (ν the frequency). The product $k_w\ r$ is the phase difference of the oscillation at distance r from the oscillation at the source.

The oscillating quantity A can be an elastic/mechanical disturbance transmitted in a material medium or a time-varying electric/magnetic field transmitted in any medium (including vacuum). The first is an elastic wave like the sound waves or the ripples on water. The latter is an electromagnetic wave.

Any time-varying (oscillating) electric field generates a time-varying magnetic field of the same time variations (frequency, waveform) and vice versa. The two of them constitute an electromagnetic wave. The intensities-vectors of the two fields are always vertical to each other, and both are vertical to the direction of the wave. This is described by classical electromagnetism, which is summarized in the Maxwell equations (Tesla 1905; Alonso and Finn 1967; Reitz and Milford 1967; Alexopoulos 1973; Jackson 1975; Panagopoulos 2013). Almost all electromagnetic technological applications, including WC, are based on classical electromagnetism. Electromagnetic waves do not need a material medium to accommodate their transmission and can be transmitted in the void as well due to some inherent property which is not yet entirely understood. We shall simply accept that EMFs/EMR can be transmitted by themselves in the void (and in material media) with the velocity of light c (which is smaller in the material media than in the vacuum/air depending on the permittivity of each medium).

In electromagnetic waves, the oscillating–propagating quantities are the electric and the magnetic field intensities (the electric and magnetic components of the electromagnetic wave). A plane harmonic electromagnetic wave is the simplest form of such a wave with electric (E) and magnetic field (B) intensities (vertical to each other and to the direction of propagation r) described by Eq. 1.4:

$$E = E_o sin\left(\omega t - k_w r\right) \qquad [1.5]$$

$$B = B_o sin\left(\omega t - k_w r\right) \qquad [1.6]$$

E_o, B_o are the amplitudes of electric and magnetic field intensities. In this case, the velocity of the wave is the velocity of light c.

The energy density (energy per unit volume) (in J/m^3) of a plane harmonic EMF/EMR in a medium is connected to its electric field intensity according to the equation:

$$W = \varepsilon\varepsilon_o E^2$$

where E (in V/m) is the intensity of the electric field or the electric component of the wave in the medium, ε is the relative permittivity of the medium ($\varepsilon = 1$ in the vacuum and in the air), and $\varepsilon_o = 8.854 \times 10^{-12}$ C^2/N·m^2 the vacuum permittivity.

The radiation intensity $\vec{J}$ in the medium (also called wave intensity, power density, or "Poynting vector") defined as the incident power per unit surface (in W/m^2, and more often in mW/cm^2, or μW/cm^2) is the product of the energy density with the velocity of the wave:

$$\vec{J} = \vec{c}W = c^2\varepsilon\varepsilon_o\vec{E}\times\vec{B} \qquad [1.7]$$

For plane harmonic waves, the wave intensity becomes:

$$\vec{J} = \vec{c}\varepsilon\varepsilon_o E^2 \qquad [1.8],$$

and the average value of its magnitude is:

$$J_{ave} = \frac{1}{2} c\varepsilon\varepsilon_o E_o^2 \quad [1.9]$$

where c is the velocity of electromagnetic waves in the medium with relative permittivity, ε (Alonso and Finn 1967). [The labeling ($^{\rightarrow}$) on the vectors A, k_w, r, λ, u, ω, E, B, J, is omitted for simplicity in most cases.]

Equations 1.7 and 1.8 show that the wave/radiation intensity (having the direction of the wave propagation) is vertical to both the electric and the magnetic fields (1.7), and in the case of plane harmonic waves it depends upon the square of the electric field intensity (1.8) (Alonso and Finn 1967; Panagopoulos et al. 2015a).

1.2.3 Superposition of Non-polarized EMR/EMFs

Consider two incoherent, non-polarized electromagnetic beams with resultant electric components E_1, E_2, reaching a certain point, P, in space at a certain moment, t, in time. Each beam consists of a great number of individual plane harmonic waves (e.g., photons) of random but discrete polarizations and phases transmitted toward the same direction. For the sake of simplicity, let us pick two individual plane harmonic waves, one from each beam. The two vectors, $\vec{E}_1$, $\vec{E}_2$ due to the different polarizations, oscillate on different planes. Because the two beams are not polarized, the polarizations of their constituent plane harmonic elementary waves vary randomly at point P each moment. The total angle ϕ between the two vectors each moment at point P is determined by the different polarizations, plus the different phases, and varies randomly in time.

The magnitude of the resultant electric field $\vec{E}$ (electric component of the resultant electromagnetic wave) of the two elementary plane harmonic waves each moment at point P is given by the equation describing the superposition of the two vectors $\vec{E}_1$ and $\vec{E}_2$:

$$E = \sqrt{E_1^2 + E_2^2 + 2E_1E_2\cos\phi} \quad [1.10]$$

E varies with time due to the temporal variations of E_1, E_2, $\cos\phi$. The average value of $\cos\phi$ is zero: $\frac{1}{2\pi}\int_0^{2\pi}\cos\phi\, d\phi = 0$, and the averages of E^2, E_1^2, and E_2^2 are $E_o^2/2$, $E_{o1}^2/2$, and $E_{o2}^2/2$, respectively (E_o, E_{o1}, and E_{o2} are the amplitudes of E, E_1, and E_2).

The magnitude of the average resultant electric field is then:

$$E_{ave} = \sqrt{\frac{1}{2}\left(E_{o1}^2 + E_{o2}^2\right)} \quad \text{or} \quad E_o^2 = E_{o1}^2 + E_{o2}^2 \,(= \text{constant})$$

and (according to Eq. 1.9):

$$J_{ave} = J_{1,ave} + J_{2,ave} \quad (= \text{constant}) \quad [1.11]$$

Even when the two component waves have the same frequency and phase, due to the randomly changing polarizations, the result is still the same.

Thus, the total time average radiation intensity due to the superposition of two (or more) rays consisting of individual plane harmonic waves of random polarizations (natural EMR/EMFs) is the sum of the two individual average intensities, and it is constant at every point. In other words, macroscopically, there is no local variation in the resultant radiation intensity, meaning there are no locations of increased or decreased intensity (Panagopoulos et al. 2015a; Panagopoulos 2017).

Radiation Intensity Versus Field Intensity of Non-polarized EMR

Although the sum average radiation/wave intensity due to superposition of natural non-polarized rays is the sum of individual average intensities, each one depending on the square amplitude of individual electric field (Eq. 1.11), the sum electric field intensity from infinite number of individual elementary waves constituting each ray (as e.g., with natural light), at any moment, approaches zero:

$$\lim_{n\to\infty}\sum_{i=1}^{n}\vec{E}_i = \vec{E}_1 + \vec{E}_2 + \vec{E}_3 + \ldots + \vec{E}_n = 0 \qquad [1.12]$$

Let us explain this in more detail: Consider many photons of natural non-polarized light superposed on each other at a particular point in space. Let us assume, for simplicity, that these photons have equal amplitudes and are of the same frequency but have different polarizations, meaning that their electric vectors have all possible orientations forming angles among each two of them from 0° to 360°. Since all possible orientations have equal probabilities, the superposition of a large number of such equal vectors applied on the same point in space will be the sum of vectors applied on the center of a sphere with their ends equally distributed around the surface of the sphere. The sum of an infinite number of such vectors (all applied on the same point – center of the sphere – and with their ends evenly distributed at all points of the spheric surface) tends to be zero.

In other words, at any given location at any moment, the sum electric field of a great number of incident photons of random polarization tends to zero because the individual vectors are in all possible directions with equal probabilities, diminishing each other when superimposed (destructive interference of electric vectors). Similarly, for the sum magnetic field: $\lim_{n\to\infty}\sum_{i=1}^{n}\vec{B}_i = 0$

Thus, the result of superposition of a great number of incident natural waves is increased radiation intensity, but negligible electric and magnetic fields approaching zero with infinite number of individual waves/photons. Since the electric forces on charged particles depend only upon the electric and magnetic field intensities ($\vec{E}$, $\vec{B}$), and not upon the wave intensity $\vec{J}$, non-polarized (and/or incoherent) EMFs/EMR cannot induce any net forced oscillations on any charged or polar particles (e.g., biological molecules). They may only induce heat, i.e., random oscillations in all possible directions due to momentary non-zero field intensities, but this does not result to any net electric or magnetic field or to any net forced oscillation of charged/polar molecules. This is an important point of our whole reasoning.

1.2.4 Superposition of Polarized and Coherent EMR/EMFs: Constructive and Destructive Interference

When two or more waves/fields of the same polarization and frequency are coherent, in other words, when their phase difference at the location of superposition is:

$$\varphi = 2n\pi, \text{ (with } n = 0,1,2,3,\ldots) \qquad [1.13],$$

the result is constructive interference, meaning that the resultant wave has an amplitude (max intensity) equal to the sum of amplitudes of the single waves that interfere at the particular location.

When two waves of the same polarization have opposite phases at another location, in other words, when their phase difference is:

$$\varphi = (2n+1)\pi \qquad [1.14],$$

then the result of their superposition is destructive interference, i.e., a wave of the same polarization but with diminished intensity (or even zero when the two amplitudes are equal).

The electrical components of two such waves (plane harmonic waves of the same polarization and frequency) reaching a certain location after having traveled different distances, r_1, and r_2, from their two coherent sources are given by the equations:

$$E_1 = E_{o1} sin\left(\omega t - k_w r_1\right) \qquad [1.15]$$

$$E_2 = E_{o2} sin\left(\omega t - k_w r_2\right) \qquad [1.16]$$

Again, the amplitude, E_o, of the resultant electric field, $\vec{E}$, (electric component of the resultant electromagnetic wave) is:

$$E_o = \sqrt{E_{o1}^2 + E_{o2}^2 + 2E_{o1}E_{o2}\cos\varphi} \qquad [1.17]$$

where the phase difference among the two vectors is: $\varphi = \frac{2\pi}{\lambda}\left(r_1 - r_2\right)$ depending, in this case, only upon the difference in the distances traveled by the two waves.

At any location where: $\varphi = 2n\pi$, Eq. 1.17 gives:

$$E_o = \sqrt{E_{o1}^2 + E_{o2}^2 + 2E_{o1}E_{o2}} \quad \left(= \left|E_{o1} + E_{o2}\right|\right) \qquad [1.18]$$

At these locations, we have constructive interference.

At any location where: $\varphi = (2n+1)\pi$, Eq. 1.17 gives:

$$E_o = \sqrt{E_{o1}^2 + E_{o2}^2 - 2E_{o1}E_{o2}} \quad \left(= \left|E_{o1} - E_{o2}\right|\right) \qquad [1.19]$$

At these locations, we have destructive interference.

The intensity of the resultant wave at any location is:

$$\vec{J} = \vec{J}_1 + \vec{J}_2 \qquad [1.20]$$

The amplitude of the resultant wave intensity will be, correspondingly:

$$J_o = c\varepsilon\varepsilon_o\left(E_{o1} + E_{o2}\right)^2 \qquad [1.21]$$

$$J_o = c\varepsilon\varepsilon_o\left(E_{o1} - E_{o2}\right)^2 \qquad [1.22]$$

(at the locations of constructive interference and at the locations of destructive interference, respectively).

Thus, at the locations of constructive interference, the electric field vectors of the two waves/fields are parallel and in the same direction, and both the resultant field and the resultant wave intensity are maximum (Eqs. 1.18 and 1.21).

For two identical sources ($E_{o1} = E_{o2}$): $E_o = 2E_{o1}$ and $J_o = 4\ c\varepsilon\varepsilon_o E_{o1}^2 = 4\ J_{o1}$

For N identical sources: $$E_o = NE_{o1} \quad [1.23]$$

and: $$J_o = N^2 J_{o1} \quad [1.24]$$

This is why a series of parallel RF/MW antennas can be used to produce high-intensity beams in certain directions (Alonso and Finn 1967), which is the case with the so-called "antenna arrays" in 5G MT technology.

At the locations of destructive interference, the electric field vectors of the two waves are anti-parallel, and thus, both the resultant field and the resultant wave intensity are minimum (Eqs. 1.19 and 1.22). For identical sources ($E_{o1} = E_{o2}$): $E = 0$, $J = 0$.

Thus, at the locations of constructive interference, the resultant electric field from N number of polarized coherent electromagnetic sources of the same polarization, frequency, and different intensities $E_1, E_2, \ldots, E_N$, is the sum electric field from all the individual sources (e.g., antennas):

$$E = E_1 + E_2 + E_3 + \ldots + E_N \quad [1.25]$$

The greater the number of coherent superimposed waves/fields (from the same or different sources), the higher and narrower the peaks (Alonso and Finn 1967). That situation can create very sharp peaks of wave and field intensities at certain locations that are not easily detectable by field meters where any living organism may be exposed to peak electric and magnetic field intensities.

Therefore, the difference between superposition of non-polarized and polarized electromagnetic waves/fields is that, in the first case, we have increased average radiation intensity but zeroed net fields at any location, while in the second case we have increased both radiation intensity and fields at certain locations where constructive interference occurs. This difference is of crucial importance for understanding the differences in biological activity between natural (non-polarized and incoherent) and man-made (polarized and coherent) EMFs/non-ionizing EMR.

Thus, polarized and coherent (man-made) EMFs (in contrast to non-polarized) possess a net electric and magnetic field at any point in space, apart from radiation/wave intensity, and this is the key point for their increased biological activity. They can produce interference effects increasing their intensities at certain locations and induce coherent and parallel forced oscillations/rotations on charged/polar molecules in living tissues (Panagopoulos et al. 2015a). For this reason, comparing man-made EMFs with natural EMFs, in terms of their bioactivity, is a flawed methodology, resulting in misleading conclusions.

1.2.5 Polarization Combined with Variability Is the Trigger for Biological/Health Effects

Throughout biological evolution, living organisms have been constantly exposed to the geoelectric and geomagnetic fields which, as already mentioned, are static and locally polarized with average intensities ~ 130 V/m and ~ 0.5 G (0.05 mT), respectively. While no adverse health effects are connected to normal exposure to these natural ambient fields, variations in their intensities of the order of ~ 20% during "magnetic storms" or "geomagnetic pulsations" due to increased solar activity, with an average periodicity of about 11 years and lasting for a few days or weeks, are connected with increased rates of animal/human health implications, including nervous and psychic diseases, hypertensive crises, heart attacks, cerebral accidents, and mortality (Presman 1977; Dubrov 1978; Panagopoulos 2013; 2019a).

All cells and intra-cellular organelles, such as nuclei, mitochondria, etc., are protected by cell membranes, and across all cell membranes there is an intense transmembrane static and locally polarized electric field of the order of ~ 10^7 V/m (average membrane width is ~ 10 nm and average transmembrane voltage ~ 100 mV). All physiological cellular functions are initiated and accompanied by endogenous electric currents consisting of ion flows through the cytoplasm and the cell membranes with corresponding changes in the intracellular ionic concentrations. These vital ionic currents and concentration changes are mediated by ion channel gating (opening and closing) in the cell membranes. Voltage-gated ion channels (VGICs) in all cell membranes switch between open and closed state whenever a change exceeding ~ 30% in the transmembrane voltage/field takes place. It is known that ~ 30 mV changes in the normal ~ 100 mV transmembrane voltage are required to change the status of the VGICs in cell membranes (from opened to closed and vice versa). Obviously no life, as we know it, could exist without proper functioning of ion channels (Weisenseel 1983; Liman et al. 1991; Nuccitelli 1992; 2003; Alberts et al. 1994; McGaig and Zhao 1997; Panagopoulos and Margaritis 2003; Panagopoulos 2013).

There are important similarities in the above two classes of natural EMFs, the terrestrial (geoelectric and geomagnetic) and the cell membrane fields: They are both static and almost totally polarized at any certain location. The terrestrial (geo)electric field and the cell plasma membrane electric field both have a direction vertical to the curved surface and toward its internal (earth, cell). Under normal/usual conditions, these fields do not induce any biological/health effects in the living organisms.

During magnetic storms, there are changes in the terrestrial static fields of the order of 20% of their normal intensities (electric and magnetic), and when the transmembrane electric field undergoes changes of the order of 30% of its normal value, the VGICs of the membrane get activated or deactivated (change their status from closed to opened and vice versa), ion flows are properly controlled, and physiological cellular effects are initiated (Panagopoulos 2013; 2019a).

A conclusion we can draw from these two natural phenomena is that biological and health effects initiate when polarized fields undergo changes of the order of 20%–30% of their normal intensities. Thus, these two similar natural phenomena provide an important clue for the bioactivity of EMFs in general: It is the combination of polarization and variability exceeding a threshold of about 20%–30% in normal average intensity that triggers biological and health effects.

1.3 MODULATION, PULSATION, AND VARIABILITY ARE INHERENT PARAMETERS OF WC EMFs

1.3.1 Information-Carrying WC EMFs. Combination of Frequency Bands

WC EMFs are not simply RF/MW EMFs. They do have an RF signal, like in emissions from radars or MW ovens, but in addition, the RF carrier signal is digitally modulated, pulsed (it is included within on/off pulses), and highly variable each moment. Even when emissions from radars include on/off pulsations as well, because their power supply has to be turned on and off for energy-saving reasons, their emissions like those from MW heating devices, do not carry information, they are invariable in time and totally repetitive/predictable. In contrast, WC EMFs carry variable information (speech, text, music, images, etc.) in the form of ELF/VLF digital modulation (bits). Moreover, their pulsations are not invariable, as in radars, but are affected by many network/communication factors making the overall signal unpredictably varying in intensity, frequency, and waveform. All this creates a random variability of the final signal each moment that makes WC EMF signals totally unpredictable in their intensity and other parameters. This whole variability lies in the ELF/ULF band (0–3000 Hz) and is always present in all WC EMFs.

Indicative RF/MW (radiation intensity) and ELF (E-field and B-field) emission measurements ± Standard Deviation (SD), at different distances from Universal Mobile Telecommunication System (UMTS) and Global System for Mobile Telecommunications (GSM) 900 and 1800 mobile phones while operating in "talk" mode and under similar conditions and signal reception, are shown in Table 1.1. We note that, while UMTS (3G/4G) in the MW band is somehow lower than both GSM

TABLE 1.1
Intensity Measurements in the MW and ELF Bands above Background Levels of UMTS (3G/4G), and 2G (GSM 900, GSM 1800), According to Distance from Source (Mobile Phone)

Distance from source (cm)	UMTS Rad. Int. 1.95 GHz (μW/cm^2)	UMTS ELF E-Field (V/m)	UMTS ELF B-Field (mG)	GSM 900 Rad. Int. 0.9 GHz (μW/cm^2)	GSM 900 ELF E-Field (V/m)	GSM 900 ELF B-Field (mG)	GSM 1800 Rad. Int. 1.8 GHz (μW/cm^2)	GSM 1800 ELF E-Field (V/m)	GSM 1800 ELF B-Field (mG)
0	232 ± 89	33 ± 8.2	3.8 ± 1.3	378 ± 59	19 ± 2.5	0.9 ± 0.15	252 ± 50	13 ± 2.1	0.6 ± 0.08
1	33 ± 10	22 ± 5.9	3.0 ± 0.7	262 ± 46	12 ± 1.7	0.7 ± 0.13	65 ± 15	6 ± 0.8	0.4± 0.07
10	19 ± 7.1	12 ± 3.1	1.5 ± 0.4	62 ± 20	7 ± 0.8	0.3 ± 0.05	29 ± 5	2.7 ± 0.5	0.2± 0.05
20	9 ± 4.1	5.3 ± 2.0	0.8 ± 0.2	32 ± 8	2.8 ± 0.4	0.2 ± 0.04	11 ± 3	0.6 ± 0.12	0.1± 0.02
30	6 ± 2.3	3.2 ± 1.1	0.4 ± 0.1	10 ± 2	0.7 ± 0.09	0.1 ± 0.02	7 ± 1	0.3 ± 0.06	0.06± 0.01
40	4 ± 1.3	2.4 ± 0.7	0.3 ± 0.1	6 ± 1	0.2 ± 0.03	0.05 ± 0.01	4 ± 0.7	0.1 ± 0.04	–
50	3 ± 1.1	1.6 ± 0.4	0.2 ± 0.05	4 ± 0.6	0.1 ± 0.02	–	2 ± 0.3	–	–
60	2.1 ± 0.8	1.0 ± 0.3	0.1 ± 0.03	2 ± 0.3	–	–	1.6 ± 0.2	–	–
70	1.8 ± 0.6	0.4 ± 0.1	0.1 ± 0.02	1.7 ± 0.2	–	–	1.3 ± 0.2	–	–
80	1.3 ± 0.4	0.1 ± 0.04	–	1.2 ± 0.2	–	–	1.1 ± 0.2	–	–
90	0.8 ± 0.3	–	–	1.0 ± 0.1	–	–	0.5 ± 0.1	–	–
100	0.5 ± 0.2	–	–	0.4 ± 0.1	–	–	0.2 ± 0.1	–	–

900 and 1800 (2G), its corresponding emissions in the ELF band are stronger. While ELF emissions from GSM 900 and 1800 mobile phones fall within the background of the stray 50 Hz fields for distances longer than 30–50 cm from the source, the corresponding UMTS emissions fall within the same background for distances longer than 70 cm. As MT base antennas are usually ~ 100 times stronger than corresponding mobile phones with similar radiation patterns in response to distance, the EMF levels in Table 1.1 correspond to base antenna emissions at ~ 100 times longer distances. For example, power density ~ 10 μW/cm^2 usually measured at 20–30 cm distances from mobile phones is usually measured at 20–30 m from corresponding base station antennas. After the installation of the 4G "UMTS Long Term Evolution" (LTE) system, base antennas and devices emit signals not only for MT but also for the Internet simultaneously, making EMF emission patterns even more complicated (and adversely bioactive). As noted, the EMF measurements in Table 1.1 are only indicative because they depend strongly on signal reception/availability, weather conditions, etc. Within metallic chambers (e.g., cars, elevators, etc.), mobile phone emissions can be significantly stronger.

Next, we shall explain the role of each parameter in the variability of the WC EMF signals.

1.3.2 Modulation, Pulsation, and Random Variability

Modulation

The simplest form of electromagnetic emission that can be manufactured is a single harmonic (sinusoidal) electromagnetic wave (described by Eqs. 1.4, 1.5, and 1.6). However, no information, such as voice, pictures, and other data, can be transmitted by such a signal alone. In order to convey information, the single-frequency signal – called a "carrier wave" – must be "modulated" by another signal which contains the information to be sent. Modulation of the RF signal by a signal containing the information (voice, message, pictures, video, data, etc.) is apparently the case in all WC EMF emissions. We may say that modulation is the information signal "loaded" on the RF carrier. The modulation signal is, in most cases, an ELF/VLF signal. There are three basic types of modulation, according to the physical parameters which characterize the carrier signal: Amplitude, frequency, and phase (Alexopoulos 1973; Lioliousis 1979; Schwartz 1990).

Amplitude modulation (AM) means that the amplitude (max intensity) of the carrier varies according to the modulating signal. The curve of the amplitude variations depicts the modulating signal. When the modulating signal can take any value in a given range, the AM is called analog. The AM radio broadcasting or the first-generation (1G) mobile phones are analog AM applications. When the modulating signal can only take discrete values, the modulation is called "digital". Usually, the modulating signal has a rectangular shape which takes the values "1" or "0" (binary system). With value "1", the carrier is emitted, while with value "0", it is not. This is the simplest case of digital amplitude modulation, called "OOK" (on-off keying). Another type of digital amplitude modulation is the Time Division Multiple Access (TDMA) applied in 2G (GSM) MT and in cordless domestic phones, referred to as Digitally Enhanced Cordless Telecommunications (DECT) phones (Schwartz 1990; Pedersen 1997; Tisal 1998; Pirard and Vatovez).

Frequency modulation (FM) means that the frequency of the carrier varies within a given range according to the modulating signal. Respectively, FM can be analog when the carrier frequency can take any value of the given range (such as in the older FM broadcasting) or digital when the carrier frequency can take only discrete values. FSK (frequency-shift keying) is a simple case of digital frequency modulation in which the carrier frequency can take only two values: One corresponding to 0, and the other to 1 of the modulating signal (Schwartz 1990; Pirard and Vatovez).

Phase modulation (PM) accordingly means that the phase of the carrier signal varies according to the modulating signal. As with AM and FM, it is analog when the carrier phase takes any value within a given range or digital when it takes only discrete values. A simple type of digital phase modulation is the binary phase-shift keying (BPSK) modulation for which the phase becomes 0° or 180° corresponding to 0 or 1 values of the modulating signal. Another type is the Gaussian

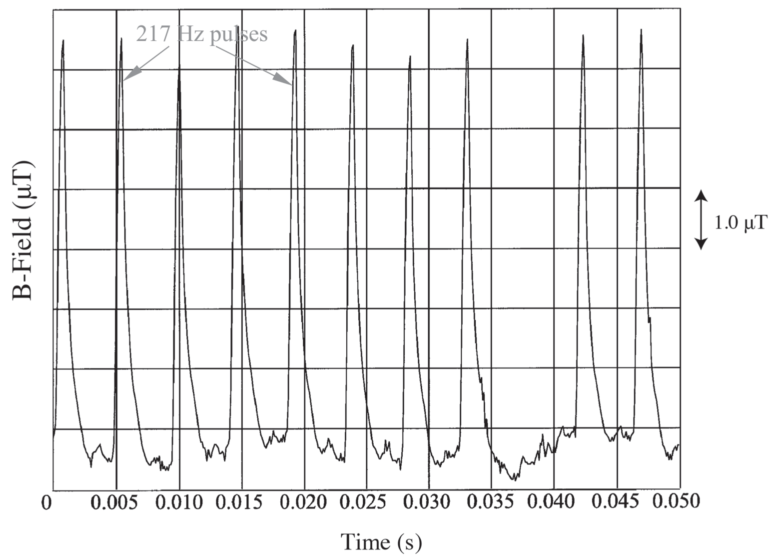

FIGURE 1.2 217 Hz pulses from a GSM mobile phone (adapted from Andersen and Pedersen 1997).

Minimum Shift Keying (GMSK) modulation applied in 2G MT and in DECT phones. GSM and DECT phones/antennas combine GMSK phase modulation with TDMA amplitude modulation (Schwartz 1990; Pedersen 1997; Tisal 1998).

In all three types of modulation, the envelope of the radiated (final) signal (amplitude, shape, and content) is modified according to the modulating signal.

Pulsation

Apart from modulation, all modern digital WC EMFs are pulsed in order to increase the density of information conveyed by the WC signal and the number of subscribers communicating simultaneously via the same antenna and occupying the same frequency band. This is called multiplexing in WC terminology. The pulses are usually (but not necessarily) rectangular with a pulse repetition rate in the ELF band, always variable in intensity and frequency, and their number increases with increasing amount of transmitted information and number of subscribers simultaneously using the same base antenna. Because the information is variable each moment (speech, text, music, images, video, Internet, etc.), and the number of users is also variable, the final signal is variable as well. For these reasons, WC EMFs are not like other RF emissions which do not carry variable information, such as pure RF signals from signal generators, or radar signals with invariable pulsations (Puranen and Jokela 1996; Pedersen 1997; Tisal 1998; Hyland 2000; 2008; Zwamborn et al. 2003; Holma and Toskala 2004; Tuor et al. 2005; Curwen and Whalley 2008; Zhou et al. 2010; Sauter 2011; Shim et al. 2013; Pirard and Vatovez; Panagopoulos 2019a).

Thus, all types of modern WC EMFs, such as from MT, DECT phones, Wi-Fi, wireless communication among electronic devices (Bluetooth), combine MW fields (with frequency usually around ~ 1–3 GHz and increasing with newer systems) as the carrier signals, with variable ELF (in most cases) fields to modulate the carrier and to increase the number of users, and the amount of transmitted information by pulsing the signals.

More specifically, 2G GSM MT EMFs, emitted by mobile phones and base antennas, except for their MW carrier signal, (900, 1800, or 1900 MHz) include a pulse repetition frequency ~ 217 Hz (Figure 1.2) plus other ELF pulsations, such as the multi-frame repetition frequency of ~ 8.34 Hz, and the Discontinuous Transmission Mode (DTX) frequency ~ 2 Hz (only in mobile phones) when the user does not speak ("listening mode"). See recorded pulsations from GSM mobile phones in Figure 1.2 and in Pedersen (1997). GSM uses the TDMA AM for the pulse amplitude, and the radiation is emitted in frames of 4.615 ms duration at a repetition rate of ~ 217 Hz. Each frame consists of eight “time slots”, and each user occupies one of them. Within each time slot, the RF carrier is phase modulated by GMSK modulation (Pedersen 1997; Tisal 1998; Hyland 2000; 2008; Zwamborn et al. 2003; Tuor et al. 2005; Curwen and Whalley 2008).

3G (UMTS) MT EMFs from mobile phones and base station antennas emit a MW carrier signal at 1950–2150 MHz with basic ELF pulsations at ~ 100 Hz (frame repetition called “Time Division Duplex”), and ~ 1500 Hz (called “Adaptive Power Control”). See recorded UMTS pulsations in Figure 1.3 and in Zwamborn et al. (2003). UMTS uses the Code Division Multiple Access (CDMA) technology for multiplexing, which assigns a special code to each user (Zwamborn et al. 2003; Holma and Toskala 2004; Hyland 2008; Curwen and Whalley 2008).

The GSM (2G) and UMTS (3G) technologies are retained also in the 4G (LTE) MT system which still uses UMTS or GSM for telephony (voice) and LTE for internet connection and other applications. A newer version of 4G called VoLTE (Voice over LTE) uses the LTE system for telephony as well, being able to handle data services and voice calls concurrently. The LTE carrier frequencies (mostly 1800–2600 MHz) differ in different countries. The 100 Hz on/off (frame) pulsations of UMTS are also used in the pure LTE (4G), and there are additional 1000 Hz (subframe), 200 Hz (synchronization signals), plus other ELF synchronization and reference pulsations (Sesia et al. 2011; Sauter 2011; Shim et al. 2013). Various LTE pulsations and random signal variability are shown in Figures 1.4–1.6.

In the 5G or New Radio (NR) system which is being deployed, the carrier frequencies are extending up to 80–100 GHz with two basic frequency ranges: 1) existing MT bands ≤6 GHz, and 2) 24.25–52.6 GHz with a tendency to increase. Moreover, 5G uses new technologies such as Multiple-Input Multiple-Output (MIMO) for multi-stream transmission and high data rates, and adaptive beam-forming by use of antenna arrays (which can be used to amplify beam intensity – see Section 1.2.4 equations 1.23, 1.24). The 100 Hz and 1000 Hz pulsations (frame, subframe) are retained, and there are synchronization and reference pulsations at ~ 6–200 Hz called Synchronization Signal Blocks (SSB) (Rappaport et al. 2013; Dahlman et al. 2018).

WLAN (Wi-Fi) and Bluetooth signals used for connection to the internet and communication among devices (portable computers/laptops, “smart” phones, printers, etc.), respectively, have main carrier frequencies around 2.45 GHz (with a tendency to increase in newer devices) and pulsations at ~ 10 Hz called beacons which are synchronization signals (Figure 1.7). DECT phones and their corresponding domestic bases emit a carrier signal of around 1880 MHz with two basic ELF

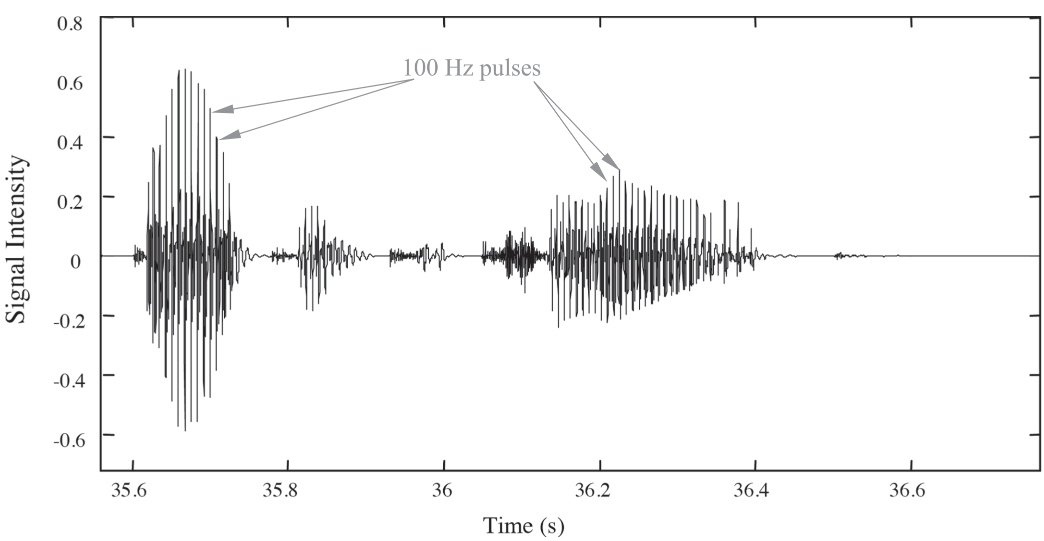

FIGURE 1.3 100 Hz “frame” pulses of a UMTS (3G/4G) mobile phone signal. Each vertical line is a pulse containing the carrier signal (adapted from Holma and Toskala 2004).

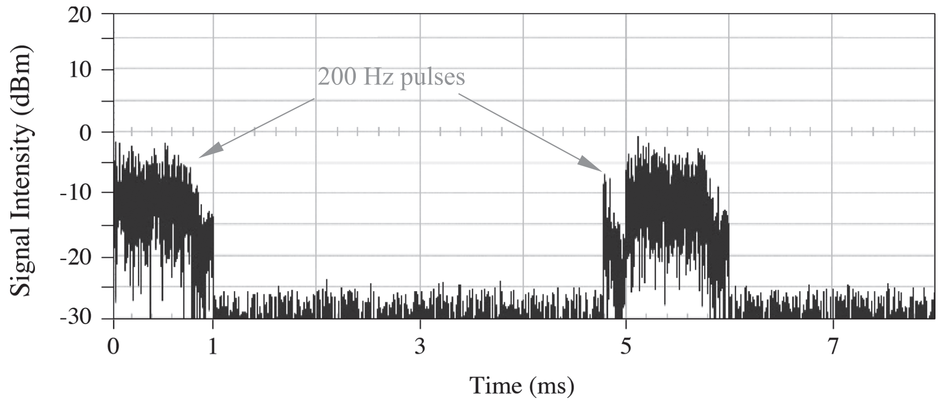

FIGURE 1.4 200 Hz pulses plus random variability in LTE (4G) signal. The variability exists also within the pulses. It seems that the synchronization signals (200 Hz) have boosted the whole corresponding subframes (subframe duration in the figure is the time among successive vertical lines) (adapted from High Performance Solutions).

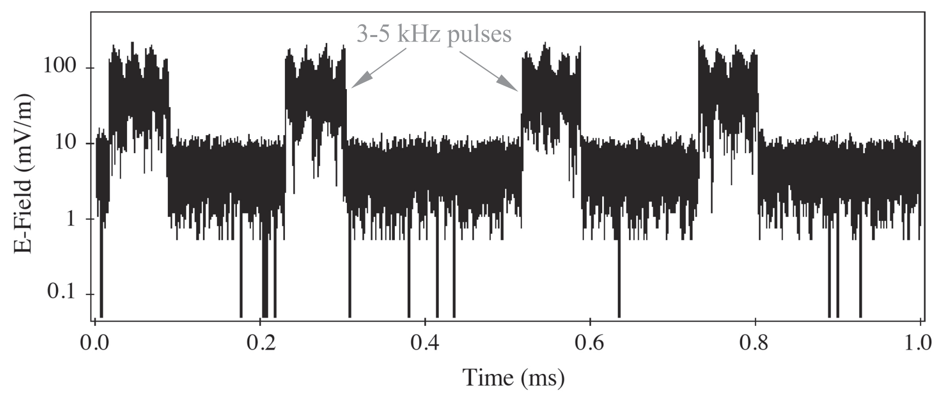

FIGURE 1.5 3–5 kHz pulses plus random pulsations from an LTE (4G) base station antenna with no traffic (adapted from Pirard and Vatovez).

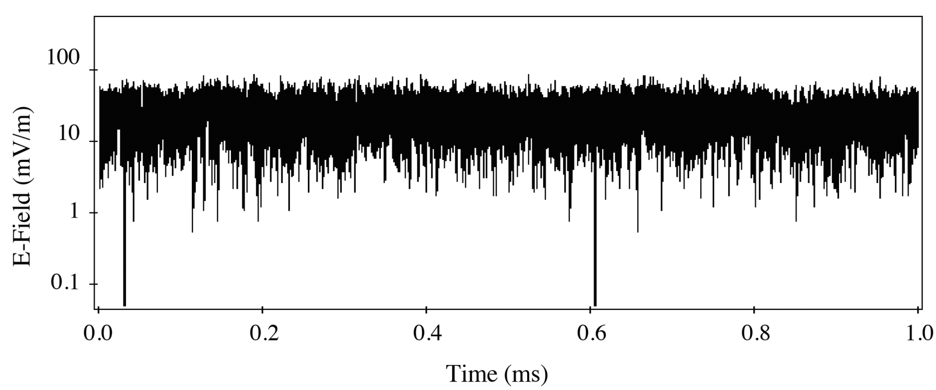

FIGURE 1.6 Random variability/pulsations of LTE (4G) base station antenna emission while communicating (downloading) (adapted from Pirard and Vatovez).

pulsations (frame repetition at ~ 100 and an additional on/off pulsation at ~ 200 Hz) (Figure 1.8). Terrestrial Trunked Radio (TETRA) antennas/devices used by emergency services emit a carrier signal of around 400 MHz with ELF/ULF pulsations at ~ 0.98, ~ 17.64, and ~ 70.4 Hz (Pedersen 1997; Hyland 2008; Curwen and Whalley 2008; Zhou et al. 2010).

The carrier (RF) and pulsing (ELF/ULF) frequencies of GSM, UMTS, LTE, DECT, Wi-Fi/Bluetooth, and TETRA are shown in Table 1.2. Both carrier and pulsing frequencies are variable in all systems. Figures 1.2–1.8 show ELF pulsations and random variability of GSM, UMTS, LTE, Wi-Fi, and DECT signals.

Random Variability

In addition to modulation and pulsing, in all modern digital WC EMFs, the envelope (final signal) is further modified (in amplitude/intensity, pulse repetition frequency, shape, etc.) due to various

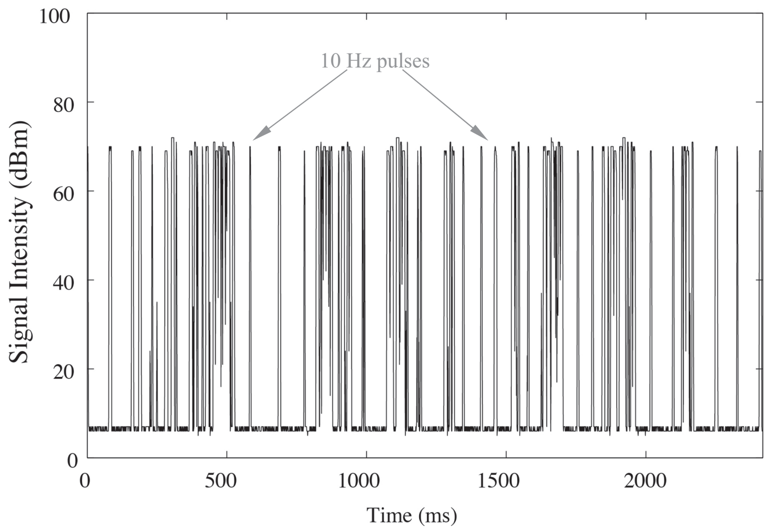

FIGURE 1.7 10 Hz pulses of WLAN (Wi-Fi) (adapted from Zhou et al. 2010).

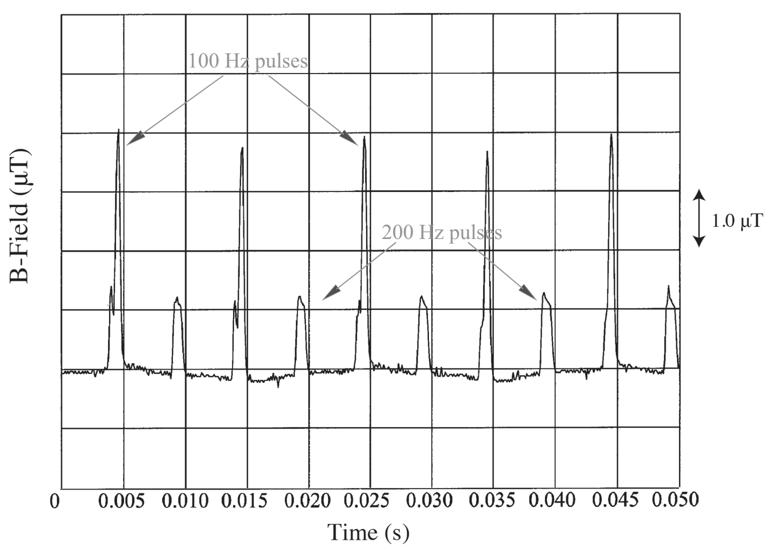

FIGURE 1.8 100 Hz and 200 Hz pulsations from a DECT phone (adapted from Andersen and Pedersen 1997).

TABLE 1.2
Basic Carrier Frequencies and ELF Pulsations of Most Common WC EMFs

WC EMF Type	Carrier Frequencies (RF)	Pulsing Frequencies (ELF/ULF)
GSM (2G MT)	900 MHz, 1800 MHz, 1900 MHz	217 Hz (frame repetition), 8.34 Hz (multi-frame repetition), 2 Hz (DTX mode)
UMTS (3G, 4G MT)	1950 MHz, 2150 MHz	100 Hz (Time Division Duplex), 1500 Hz (Adaptive Power Control)
LTE (4G MT/WC)	1.8 - 2.6 GHz (in most cases)	100 Hz (frame repetition), 1000 Hz (subframe repetition), 200 Hz (synchronization pulses)
NR (5G MT/WC)	Frequency range 1: ~0.7–6 GHz Frequency range 2: 24.25–52.6 GHz	100 Hz (frame repetition), 1000 Hz (subframe), 6–200 Hz (synchronization pulses)
DECT	1880 MHz	100 Hz (frame repetition), 200 Hz (energy saving on/off)
WLAN (Wi-Fi), Bluetooth	2450 MHz	10 Hz (beacons)
TETRA	400 MHz	17.64 Hz (frame repetition), 0.98 Hz (multi-frame repetition), 70.4 Hz (burst repetition)

physical imperfections in the electronic circuits and other parameters such as heat, noise, interference with various other electromagnetic sources, etc., plus multiple other variable physical parameters during transmission. Each moment when the number of users performing different tasks (voice, data, etc.) increases, more pulses are emitted, each one accommodating a different user or task. The final signal from both base antennas and devices depends also on additional uncontrollable parameters, such as the position of each user with respect to the base antenna, air conductivity, signal availability/reception at the specific place and time, etc. All these functions and uncontrollable parameters result in intense unpredictable variability of the final signal with variable frequency, mainly in the ELF/ULF band (see Figures 1.2–1.7). This random ELF/ULF variability is perhaps the most intense and bioactive parameter of the WC EMF emissions (in combination with the fact that the signals are totally polarized) (Holma and Toskala 2004; Panagopoulos et al. 2015b; Panagopoulos 2019a; Pirard and Vatovez).

Thus, apart from the ELF/VLF pulsing and modulation frequencies always included in the WC EMFs, during any signal transmission, there are additional continuous unpredictable changes due to the varying physical parameters, the varying information transmitted each moment, the varying number of users at various locations, environmental factors, etc. Especially with mobile phones/antennas, there are continuous sudden unexpected changes in intensity due to changes in location, number of subscribers using the network each moment, air conductivity changes, etc. These sudden unexpected changes in the final signal may exceed by 100% and even more the average intensity. Finally, for energy-saving reasons, when GSM handsets operate in DTX ("listening") mode, the average emitted power is much less (about one tenth) than when the user speaks ("speaking mode") (Pedersen 1997; Panagopoulos et al. 2004; Hyland 2008). The described final random variability of WC signals can be easily recorded by any RF field meter measuring power density in any urban environment or close to any WC device. The reading of the instrument shows continuous unexpected changes in the measured power density, usually ranging in urban environments between 0.01 and 1 $\mu W/cm^2$ and reaching ~ 10 $\mu W/cm^2$ in closer proximity to antennas. This variability lies mainly in the ULF band (0–3 Hz). The random variability of the final signal can be seen in Figures 1.3 and 1.6 for UMTS (3G/4G) mobile phones and LTE (4G) base antennas, respectively.

Due to the above inherent variability of all WC EMFs, any EMF/EMR measurements can only be representative for average or peak values. The variability becomes more intense in the near field of the emitting devices/antennas (Panagopoulos et al. 2016; Panagopoulos and Karabarbounis 2020). For this reason, health organizations such as the IARC (2013) have recommended that experimental studies on the effects of WC EMFs should be performed with invariable simulated signals emitted by generators or test phones. But exactly because of this inherent variability, it is impossible to simulate the real emissions by use of invariable emissions of fixed parameters (such as fixed intensity, frequency, and pulsation), and when such simulated EMFs are used in experiments, they are significantly less bioactive than real-life WC EMFs. Thus, the simulated signals are very different and much less effective in inducing adverse biological/health effects (Panagopoulos et al. 2015b; Panagopoulos 2017; 2019a; Pall 2018; Leach et al. 2018; Kostoff et al. 2020). Even though the measurements of real WC signals can only be representative, there is actually no need for "exact" measurements. Average and peak measurements are enough to predict bioactivity (Panagopoulos et al. 2016; Panagopoulos and Karabarbounis 2020).

In fact, health agencies', including the IARC, acceptance of simulated exposures with fixed parameters for studying the effects of WC EMFs and the exclusion of the studies having used real-life exposures is one of the most serious flaws in the evaluation of WC EMF bioactivity by these agencies, resulting in the underestimation of the adverse effects (Panagopoulos et al. 2015b). As a result, about 50% of the experimental studies having employed simulated WC signals (in line with IARC's recommendation) do not find any effects, while more than 95% of the studies employing real-life WC exposures from commercially available devices or antennas find effects (Panagopoulos et al. 2015b; Panagopoulos 2017; 2019a; Gulati et al. 2016; Zothansiama et al. 2017; Leach et al. 2018; Kostoff et al. 2020).

1.4 MOST MAN-MADE EMF EXPOSURES ARE NON-THERMAL

1.4.1 Energy of EMF-Induced Molecular Oscillations

In living tissue, most (bio)molecules are polar, (meaning they have a positive side and a negative side separated by some distance of atomic/molecular dimensions, as e.g., water molecules) or carry a net electric charge. Thus, any man-made (polarized) oscillating EMF (and corresponding EMR) induces a forced oscillation on each of these charged/polar molecules and transfers to each of them a tiny part of its energy. This forced oscillation is linear in the case of molecules bearing a net electric charge or rotational in the case of polar molecules.

It seems that a main mechanism of action for both ELF and purely RF man-made (polarized) EMFs is this forced oscillation/rotation of charged/polar particles (Metaxas 1991; Panagopoulos et al. 2000; 2002; 2015a; 2020; 2021).

This induced oscillation will be of greatest amplitude on the smallest (and lightest) mobile particles which carry a net electric charge, i.e., the mobile ("free") ions that exist in large concentrations in all types of cells and extracellular aqueous solutions determining practically all cellular/biological functions (Alberts et al. 1994; Panagopoulos and Margaritis 2003). The induced oscillation will be much smaller on the polar water molecules and even of negligible amplitude on the much larger polar biological macromolecules such as proteins, lipids, nucleic acids, etc., which are, in most cases, bound with other molecules.

The amount of energy absorbed by a single mobile ion in biological tissue will manifest itself as kinetic energy of the forced oscillation induced on that particle. The maximum kinetic energy of such an oscillation is:

$$\in(\max) = \frac{1}{2} m_i u_o^2 \qquad [1.26]$$

where, m_i is the ion mass (e.g., for Na^+ ions $m_i \cong 3.8 \times 10^{-26}$ kg), and u_o is the particle's maximum velocity acquired by the forced oscillation.

1.4.2 Non-thermal Exposures. A New Biophysical Constant

Significant experiments in the mid-1970s with, what was at the time, a novel technique called "patch-clamp" allowed the measurement of ion currents through open ion channels in cell membranes

(Neher and Sakmann 1992; Stryer 1996). This technique is widely used today in the study of ion channels (Cecchetto et al. 2020; Zheng et al. 2021). It was found that the electric current through an open sodium channel is of the order of 4×10^{-12} A when the transmembrane voltage is around 100 mV. That means 2.5×10^7 Na^+ ions per s flow through an open channel. Taking the channel's length equal to the membrane's width $\cong$ 10 nm = 10^{-8} m and accepting that the ions pass through the channel in single file (Palmer 1986; Panagopoulos et al. 2000), we find that the transit time of every Na^+ ion through the Na^+ channel is ~ 0.4×10^{-7} s, and thus, the ion velocity through the channel is: $u = 2.5 \times 10^7 \times 10^{-8}$ m/s $\Rightarrow u = 0.25$ m/s (see also Chapter 11).

Considering that this velocity is acquired under the force of the transmembrane electric field, which is a huge field (~ 10^7 V/m), any other velocity acquired by any charged particle/molecule within biological tissue due to any externally applied EMF will normally be several orders of magnitude smaller than that. Thus, we can reasonably accept that this ion drift velocity through an open ion channel represents an upper limit for the maximum velocity an ion can acquire within living tissue. Indeed, the velocity of an oscillating ion, according to the ion forced oscillation mechanism, is found for all frequencies and for all possible field intensities of environmentally existing polarized EMFs to be much smaller than 0.25 m/s (see Chapter 11 and Panagopoulos et al. 2021). Thus, the max ion velocity in biological tissue is:

$$u_o = 0.25 \text{ m/s} \qquad [1.27]$$

This maximum velocity (and corresponding kinetic energy) of the mobile ion was calculated independently of any externally applied EMF, and it is similar for any living system because cells in most organisms (e.g. in all animals) have identical cell membranes and ion channels. It, thus, represents a biophysical constant which is important for electromagnetic interactions in living tissues.

From Eq. 1.26, we get that the maximum kinetic energy corresponding to u_o, is: $\in(\max) \approx 1.2 \times 10^{-27}$ J. This is respectively an upper limit for the energy that may be absorbed by a single sodium ion due to the interaction with an applied EMF (which is usually several orders of magnitude smaller).

The Thermal Energy

The average kinetic energy of a mobile ion (and of any free molecule) of mass, m_i, and velocity u_{kT} due to thermal motion for tissue temperature T is (Alexopoulos 1962; Mandl 1988; Panagopoulos et al. 2013b):

$$\in_{kT} = \frac{1}{2} m_i u_{kT}{}^2 = \frac{3}{2} kT \qquad [1.28]$$

which gives:

$$u_{kT} = \sqrt{\frac{3kT}{m_i}} \qquad [1.29]$$

(T the tissue absolute temperature in K, and $k = 1.381 \times 10^{-23}$ J·K^{-1} the Boltzmann's constant). For Na^+ ions ($m_i \cong 3.8 \times 10^{-26}$ kg) and $T = 310$ K (human body temperature 37°C) we get: $\in_{kT} \cong 6.4 \times 10^{-21}$ J, and $u_{kT} \cong 0.58 \times 10^3$ m/s.

It follows that the thermal velocity and energy of a sodium ion in living tissue at human body temperature are ~ 2.3×10^3 times and ~ 5.3×10^6 times greater, respectively, than the maximum velocity and kinetic energy that could ever be acquired by this ion due to any expected applied EMF. In fact, as explained, the differences are several orders of magnitude greater in the case of environmental EMF exposures. This result is in agreement with experimental studies showing that the vast majority of recorded EMF bioeffects are non-thermal (Carpenter and Livstone 1968; Adey 1981; 1993; Gründler 1992; Kwee and Raskmark 1998; Velizarov et al. 1999; Panagopoulos et al. 2007a; 2007b; 2010; and reviews Walleczek 1992; Goodman et al. 1995; Creasey and Goldberg 2001; Belyaev 2005; Panagopoulos and Margaritis 2009; Phillips et al. 2009; Behari 2010; Panagopoulos 2011; 2017; 2019a; 2019b; 2020;

Wust et al. 2021). Moreover, the above result is in agreement with the suggested mechanism of action of EMFs on cells (Panagopoulos et al. 2000; 2002; 2015; 2020; 2021). Thus, environmental EMF exposures (even in today's EMF-polluted environment) do not normally result in increasing tissue temperature.

1.4.3 Thermal Exposures

Naturally, heating of any material occurs when the absorbed radiation has a frequency close to the infrared band (~ $3 \times 10^{11} - 3 \times 10^{14}$ Hz). This comes from the fact that the emission and absorption spectrum of a "black body" has a peak mainly in the infrared and, secondarily, in the visible band of the electromagnetic spectrum. According to Kirchhoff's theorem, any material body of temperature T absorbs and emits radiation at the same frequencies/wavelengths as a "black body" at the same temperature (Alexopoulos 1962; Alonso and Finn 1967; Panagopoulos and Margaritis 2003).

Heating of materials occurs also by artificial exposures to MWs of high intensity/power (≥0.1 mW/cm^2) and frequency (≥1 GHz), such as in MW ovens, which emit MW EMR at 2.45 GHz with a power of ~ 1000 W focused within the metal cavity of the oven. This is a well-established phenomenon in physics called "microwave heating" (Metaxas 1991; Clark et al. 2000; Olaniyi 2017). Man-made MW radiations used in WC and other applications with frequencies 1–10 GHz may start inducing slight temperature increases in living tissue when their power density increases more than ~ 0.1 mW/cm^2 (Panagopoulos and Margaritis 2003; Panagopoulos et al. 2013b). Environmentally existing MW exposures mainly due to mobile/cordless phones and corresponding antennas, Wi-Fi, wireless connections (Bluetooth), etc., range between 0.001 μW/cm^2 and ~200 μW/cm^2 (very close to mobile phones) (Panagopoulos et al. 2010; Panagopoulos 2017; 2019b; Wongkasem 2021).

The induction of small temperature increases of the order of 0.15–0.3°C has been reported after exposure of biological samples (*Caenorhabditis elegans*) to continuous-wave 1 W, 1 GHz emitted by a generator within an exposure chamber (Dawe et al. 2006). In real exposure conditions, a GSM mobile phone in "talk" mode at 0–1 cm distance (0.2–0.3 mW/cm^2, 0.9, or 1.8 GHz) was not found to induce heating at a 0.05°C level within the mass of food for fruit flies in exposed glass vials (Panagopoulos et al. 2004; 2007a; 2007b; 2010). Similar non-thermal findings are also presented by many studies referenced above (Carpenter and Livstone 1968; Kwee and Raskmark 1998; Velizarov et al. 1999; Belyaev 2005; Wust et al. 2021). A UMTS mobile phone at 1–2 cm distance in "talk" mode (~ 0.1 mW/cm^2, ~1.95 GHz) was found to increase the temperature in 5.6 ml blood cultures after 25 min exposure by 0.1–0.2 °C (Panagopoulos 2019b; 2020). Human exposures from base station antennas at distances ≥10 m are normally of significantly lower power densities than a mobile phone at 0–1 cm proximity. Thus, in most cases, man-made EMFs at environmentally existing levels are unlikely to induce significant temperature increases in biological tissue, not even at the level of 0.1–0.3°C; however, newer WC technologies and especially 5G with higher MW frequencies and intensities may do (Neufeld and Kuster 2018; Thielens et al. 2018; 2020).

In order for the EMF exposures to cause heating, they should be millions of times more powerful than most environmental ELF EMFs and significantly more intense than environmentally existing RF EMFs, such as, for example, the ELF fields in close proximity to high-voltage/power transformers or power lines or the RF fields within a MW oven focusing all of its radiating power within its cavity. GSM (2G), UMTS (3G/4G), or LTE (4G) mobile phones (with average radiating power ~ 0.1–1 W) at a few cm distance or more, or even a corresponding base station antenna (~ 10–100 W) distributing their power in all directions within wide angles, would not cause any heating apart from 0–0.3°C when used in contact or very close proximity during "talk" mode (or video calling) and after several min of exposure.

The mechanism of heating biological tissues is as follows: Due to friction during the induced forced oscillation of the charged/polar molecules (and especially mobile ions), a part of the particle's kinetic energy is converted to heat. The damping coefficient of electrolytes increases (conductivity decreases) with higher (MW) frequencies (Chandra and Bagchi 2000). This results in increased friction of the oscillating molecules and slight tissue heating which may become significant for increasing frequency and power. While with 2G, 3G, 4G mobile phones (ν ~ 1–2 GHz), the heating effect, even with the device in close proximity to the body, ranges from 0°C to 0.2°C; newer WC radiation types, with increasing frequencies and especially 5G combining significantly higher frequencies (up to 80–100 GHz) and denser radiation beams of anticipated greater intensity, may produce significant thermal effects in addition to the already existing non-thermal induced by the ELF pulsation, modulation, and variability (Neufeld and Kuster 2018; Thielens et al. 2018; 2020; Panagopoulos 2020; Wongkasem 2021). Thus, RF/MW EMF exposures with frequencies approaching infrared and with high enough power density (≥0.1 mW/cm^2) may cause tissue heating.

The absorbed power per unit volume can be written according to tissue specific conductivity (σ) and electric field intensity (E) as, (see Section 1.5, Eq. 1.34):

$$\frac{dP}{dV} = \sigma E^2 \quad [1.30]$$

As the specific conductivity of tissue depends on the frequency ν of the field, the absorbed power P by living tissue will also depend on frequency. In MW heating, the absorbed power by a material (e.g., living tissue) per unit volume dP/dV increases with increasing wave/field frequency ν, the dielectric loss factor ε' of the material, and the electric field within the material E according to the equation (Metaxas 1991; Clark et al. 2000; Olaniyi 2017):

$$\frac{dP}{dV} = 2\pi \nu \varepsilon_o \varepsilon' E^2 \quad [1.31]$$

Thus, the MW heating effect increases as the EMF frequency (ν) increases approaching the low limit of infrared, and as the EMF power density (depending on E^2 according to Eq. 1.8) increases, resulting in measurable heating. Apart from the forced oscillation of charged/polar molecules, the MW heating effect seems to be related with some kind of not yet fully explored resonant absorption mechanism when the MW EMF frequency approaches the low limit of infrared (and accordingly the wavelength reduces to a few mm – "mm-waves"). The more the EMF frequency approaches infrared and the EMF power density increases, the more significant becomes the effect, resulting in measurable heating. This is probably related to the natural phenomenon expressed by Kirchhoff's law that any material body absorbs EMR at the same wavelengths/frequencies at which this body emits electromagnetic radiation. These wavelengths/frequencies for all bodies are mainly in the infrared and, secondarily, in the visible part of the electromagnetic spectrum, as described above (Alexopoulos 1962; Panagopoulos and Margaritis 2003).

5G MT employs higher MW carrier frequencies (called mm-waves) in order to accomplish higher quality of simulations (data transfer). But with higher frequencies, the heating of exposed living tissues increases (Eq. 1.31), while penetration through different materials (e.g., air, buildings, etc.) decreases (Eq. 1.2). In order to overcome the low penetration, the number of antennas must be significantly increased, and the intensity of the emissions as well. Under such conditions, thermal effects in exposed humans cannot be excluded in addition to the already existing non-thermal effects. Studies have theoretically predicted the induction of significant thermal effects (Neufeld and Kuster 2018; Thielens et al. 2018; 2020). These facts further justify the concerns expressed by the scientific community against the installation of 5G (Hardell and Nyberg 2020; Kostoff et al. 2020; Panagopoulos 2020).

1.5 MEASURING INCIDENT EMFs IS MORE RELEVANT THAN SAR

1.5.1 Analysis of the SAR

SAR (in W/kg) is defined as the incremental power dP absorbed by an incremental mass of tissue dm contained in a volume element dV of a given density $\rho = dm/dV$ (in kg/m^3) (NCRP 1986):

$$SAR = \frac{dP}{dm} \quad [1.32]$$

Eq. 1.32 can be expressed according to tissue conductivity, density, and internal electric field, or according to tissue specific heat and temperature increase.

SAR According to Tissue Conductivity

By use of the Ohm's law:

$$j = \sigma E \qquad [1.33]$$

where j is the electric current density (in A/m^2) within the tissue due to the internal electric field E, and σ is the tissue specific conductivity (in S/m) and assuming certain quantities to be constant within the tissue, Eq. 1.32, after operations, becomes:

$$SAR = \frac{\sigma \cdot E^2}{\rho} \qquad [1.34]$$

which is equivalent to Eq. 1.30.

Eq. 1.34 is frequently reported in papers for defining and estimating SAR, but its derivation is never described or considered. Actually, Eq. 1.34 cannot be derived unless certain physical quantities are assumed to be constant. This, of course, is a simplification that minimizes its validity. To address these issues, we must see how this formula is derived.

Derivation of Eq. 1.34

Neglecting thermal losses, the absorbed electric power dP can be expressed as the power of an electric current i (generated within the tissue by the applied EMF) flowing vertically across an area S, $dP = d\Psi \cdot i$, where $d\Psi$ is an incremental voltage induced by the EMF exposure. Then, Eq. 1.32 becomes: $SAR = d\Psi \cdot i / dm$, which can be written as: $SAR = \frac{d\Psi \cdot i \cdot S}{dm \cdot S}$, or $SAR = \frac{d\Psi \cdot j \cdot S}{dm}$, where $j = i/S$ is the current density across the area S. Since $d\Psi = E\, dr$, where E is the generated electric field within the tissue and dr is a displacement of electric charge as part of the current i, we get: $SAR = \frac{E \cdot dr \cdot j \cdot S}{dm}$. Considering that $dr{\cdot}S$ is the volume dV defined by the area S and the charge displacement dr containing tissue mass dm, and dm/dV is the tissue density ρ, assuming it is constant within the volume dV, the previous relation becomes $SAR = {j \cdot E}/{\rho}$, and replacing j with $\sigma\, E$ due to Ohm's law (Eq. 1.33), we reach the desired formula (Eq. 1.34): $SAR = {\sigma \cdot E^2}/{\rho}$.

It is obvious that in the above operations, the quantities i, j, S, E, ρ, and σ were assumed to be constant within the incremental volume dV, and, moreover, it is obvious that Eq. 1.34 refers to this volume only. In any other volume outside dV, SAR has a different value and must be calculated separately. By applying Eq. 1.34 to the whole volume of an animal, organ (e.g., eye), a group of organs (e.g., head), or even a single cell, it is assumed that j, E, ρ, and σ are constant within those volumes. This, of course, is an oversimplification, as every organ or group of organs consists of many different tissues, and all the above quantities vary significantly between different tissues and even within a single type of tissue and within a single cell (Panagopoulos et al. 2013b).

In particular, specific conductivity varies significantly among different tissues. For example, at a frequency of 1 GHz, specific conductivity in different tissues of the human body varies from about 0.04 S/m (bone marrow) to about 2.45 S/m (cerebrospinal fluid). Even within a single cell, specific conductivity can have huge variations from 10^{-7} S/m in the cell membrane to 0.5–1 S/m in the cytoplasm (Foster and Schwan 1989; Fear and Stuchly 1998).

In addition, the available data on tissue conductivity are collected from measurements on dead animals (Schwan 1957; 1963; Gabriel et al. 1996a; 1996b). The variations become significantly greater in live animals. Conductivity values in the ELF band of up to ~ 300% higher than those previously reported by Schwan (1957; 1963) were measured in porcine organs of just sacrificed animals. The differences from the previously known corresponding conductivity values were attributed to the fact that the organs were still alive and filled with blood during the measurements in contrast to the previous studies which were performed on dead organs. It was found that within an hour from animal sacrifice, the conductivities of different organs/tissues decreased by up to 50% of their original values in the alive animal (Spottorno et al. 2008; 2012), which is absolutely reasonable. These findings raise serious questions about the validity of tissue conductivity data measured before and their dependence on frequency. Moreover, the conductivity of the various organs – especially of the brain – in all animals changes with age. The conductivity of a young child's brain is almost double the conductivity of an adult's brain, resulting in almost double radiation absorption and SAR (Peyman et al. 2001; Christ et al. 2010).

Finally, human tissue density varies from about 900 kg/m^3 (fat) to about 1200 kg/m^3 (tumor) between different soft tissue types and reaches a value of about 1800 kg/m^3 for bones (Gabriel et al. 1996b).

Thereby, Eq. 1.34 provides a poor expression/definition of SAR because of the large variations of the related quantities, and any estimating method for SAR based on Eq. 1.34 includes very large uncertainty. Eq. 1.34 actually applies only within incremental volumes dV significantly smaller than single cells. Applying Eq. 1.34 on whole organs (e.g., heart, spleen, eye, etc.), groups of organs (e.g., head), or on whole animals by using average conductivity, density, and internal field values can be very misleading, as it grossly underestimates the local microscopic variations of these parameters which determine the potential biological effects.

SAR According to Tissue Specific Heat

For a homogeneous medium (thus, neglecting density and tissue-type variations) with specific heat c_h, [in J/(kg·K)] (thus, neglecting also any variations in specific heat) and by use of a form of the calorimetry law,

$$\frac{dQ}{dt} = mc_h \cdot \frac{dT}{dt} \qquad [1.35]$$

Eq. 1.32 becomes:

$$SAR = c_h \cdot \frac{dT}{dt} \qquad [1.36]$$

where dQ/dt is the radiation power transformed into an amount of heat dQ within the tissue mass m, producing a temperature increase dT during an incremental time interval dt.

For a measurable temperature increase δT during a measurable time interval δt, Eq. 1.36 would be written as:

$$SAR = c_h \cdot \frac{\delta T}{\delta t} \qquad [1.37]$$

Since variations in specific heat within living tissue are much smaller than corresponding variations in conductivity (Gabriel et al. 1996a; 1996b; Haemmerich et al. 2005), resulting in much more uniform temperature than electric field distribution, Eq. 1.37 provides a better way for SAR estimation and, therefore, definition (Panagopoulos et al. 2013b).

In addition, while differences in internal electric field intensity are retained during the whole exposure period as they depend on tissue permittivity, which has large variations even within a single cell, differences in temperature between different parts of a tissue or organ disappear a short time after the beginning of a constant exposure, and temperature gets evenly distributed within a whole organ or even body. Moreover, while tissue conductivity and permittivity/internal electric field are reported to change significantly with different frequencies of the applied EMF/EMR (Gabriel et al. 1996a; 1996b), specific heat is independent from the applied field and depends only on tissue properties. In case of exposure to WC EMFs, which include several different frequencies (carrier, pulsing, modulation), conductivity and internal field intensity become even more variable, and their accurate estimation even more complicated, while specific heat is constant.

Even if we consider a single frequency and additionally neglect internal field intensity and density differences, spatial conductivity variations alone result in considerably greater variability of SAR when calculated by Eq. 1.34 than by Eq. 1.37. For example, most organs/parts of the human/animal body contain both muscle and fat tissues. While at 1 GHz muscle specific conductivity (~ 1.006 S/m) is about 1,760% higher than fat specific conductivity (~ 0.054 S/m), muscle specific heat (~ 3.5 kJ/kg·K) is only 56% higher than fat specific heat (~ 2.3 kJ/kg·K). This would result to a ~ 1,700% larger variability in the SAR of this specific organ or part of the animal body when estimated by Eq. 1.34 than when estimated by Eq. 1.37. At lower frequencies, conductivity variations increase considerably, resulting in an even larger variability in the SAR calculation, while specific heat has the same value. For example, at 10 MHz, the above difference in SAR variability (~ 1,700%) between Eq. 1.34 and Eq. 1.37 becomes ~ 2,125% (or 21.25 times greater according to Eq. 1.34 than according to Eq. 1.37) (Leonard et al. 1984; IEEE 2002). If we add variations in internal electric field intensity and tissue density we may have hundreds of times greater variability in SAR values according to Eq. 1.34 than according to Eq. 1.37. Thus, while variation in SAR calculation according to Eq. 1.37 is restricted to measurement errors and the assumption that c_h has the same value throughout the tissue, which somehow can be tolerated, corresponding variation in SAR according to Eq. 1.34 includes similar errors plus tenths or even hundreds of times greater variability. This shows that the only way to reliably estimate SAR is by macroscopically measuring the temperature increases – if any – within biological tissue according to Eq. 1.37 (Panagopoulos et al. 2013b).

In fact, Eqs. 1.36 and 1.37 are also inaccurate, as it is assumed that all power absorbed by the exposed biological tissue is converted into heat, which, of course, is not true either. In the non-thermal effects, the power absorbed by mobile ions that are forced to oscillate in phase with the external field can be converted to gate electrosensitive ion channels (VGICs) by exerting electric forces on their channel sensors (Panagopoulos et al. 2000; 2002; 2015a; 2020; 2021). But, as we showed that the absorbed energy of these forced oscillations is more than millions of times smaller than the thermal energy of the same particles, once we have measurable heating, we may assume that this is by far greater than any other non-thermal energy absorption.

From the above analysis, it follows that SAR actually applies only to thermal effects, and it actually expresses the rate by which electromagnetic energy from an incident electromagnetic wave/field is converted into heat within living tissue. But, as already explained (Section 1.4), man-made electromagnetic fields at environmentally existing intensities do not normally induce measurable heating within exposed living tissue. Thus, SAR is not a proper metric to describe the biological activity of man-made electromagnetic fields at environmental intensities.

1.5.2 SAR Estimation Methods

SAR is estimated by 1) insertion of micro-antennas/probes into the tissue to detect the internal electric field. Assuming the conductivity and the density of the tissue to be constant, SAR is computed by Eq. 1.34; 2) insertion of miniature thermal probes into the tissue to detect changes δT in the temperature caused by the exposure during a time interval δt, assuming the tissue is homogeneous with known specific heat. Then SAR is computed by Eq. 1.37; 3) numerical modeling, such as the Finite Difference Time Domain (FDTD) method, simulating the spatial distribution of the absorbed energy within an object and computing SAR by Eq. 1.34 (Moulder et al. 1999).

Apart from the disadvantage of the first method regarding oversimplification of Eq. 1.34, in both the first and second methods, the insertion of needles/probes in living tissue disturbs its physiological function and distorts its physical properties in unpredictable ways. Moreover, in the case of live animals, it causes trauma and pain. Such methods are improper to be used in live animals and may only be used in *in vitro* experiments with cell cultures.

Numerical modeling, such as the FDTD method, which is considered the best, numerically simulates the energy absorption within the tissue by use of special computer programs, dividing the tissue volume into cubes (voxels), and assigning each of them certain values of conductivity, permittivity, and density. Then SAR is (again) computed by Eq. 1.34. Because conductivity, permittivity, and density are assumed to be constant within each voxel, this method, like the first one, is a simplification. This explains why earlier SAR estimates used in the currently accepted criteria for whole body average SAR (ICNIRP 1998; 2020) are questioned by more recent and more accurate FDTD calculations (Wang et al. 2006; Flyckt et al. 2007; Gandhi et al. 2012).

All methods of simulation, no matter how much improved, will always be highly simplified compared to the complexity of living tissue because they can never take into account the countless microscopic variations in its physical parameters. Modeling living tissue by attributing average dielectric values in whole animals or organs has been a method applied by engineers treating living tissue as an inanimate material. Such methods highly underestimate the potential biological effects which depend on significant variations of dielectric properties at microscopic level and are not taken into account by average values. Unfortunately, such simplistic methods continue to dominate in EMF dosimetry (ICNIRP 1998; 2020; Behari 2010; IARC 2013; Wongkasem 2021).

In conclusion, all the existing methods for SAR estimation, especially those based on Eq. 1.34, have serious deficiencies. Actually, only the second method, which is based on measurable tissue heating, is reliable to be applied only in cell cultures. Finally, all methods for SAR estimation are highly complicated and time-consuming, so that SAR cannot be readily measured/calculated by use of the equipment of an ordinary EMF laboratory. In other words, SAR is not only a flawed metric but impractical as well.

1.5.3 Incident EMF

A more precise and practical EMF exposure metric than SAR is the incident radiation/field intensities on the surface of the exposed biological tissue at the various frequency bands (RF, ELF, VLF, etc.) plus the additional physical parameters of the field and the exposure which can readily and accurately be known, such as pulse and carrier frequency, exposure duration, modulation, waveform, etc., as measured by reliable radiation/field meters, frequency meters, and spectrum analyzers. (Panagopoulos et al. 2013b)

As already explained, today there are thousands of studies corresponding specific biological effects to specific radiation/field intensities at the different frequency bands plus the other exposure parameters. Therefore, one can approximately predict the biological effect by knowing these field/exposure parameters, which can be readily and objectively measured. An example of different GSM intensities inducing DNA fragmentation in fruit fly ovarian cells for 6 min exposure is found in Panagopoulos et al. (2010).

Any inaccuracy in the intensity measurement, especially of the highly variable WC EMFs, and especially in the near fields, would be further increased in a corresponding SAR estimation. More specifically, if the electric field intensity E varies significantly, the corresponding SAR value depending on E^2 (according to Eq. 1.34) will include the square of this variation plus the variation in the conductivity and density of the biological tissue. Moreover, the SAR will refer to the absorbed field, which introduces an additional error in its estimation than in the incident field which is directly measured by any reliable instrument.

Intensity measurements of incident WC EMFs, and especially in the near field, may, indeed, include errors due to the described increased variability (see Section 1.3) and even possible capacitive coupling between the antenna/device and the sensor of the field meter. The error can be effectively minimized by a) using near-field probes that are now available in the market, b) increasing the number of measurements and reporting average intensity and SD and even excluding certain unrealistically high measurements which could possibly be attributed to capacitive coupling. This provides a representative estimation of the incident field. "Accurate" estimation of the instant intensity of WC EMFs, especially in the near field, has no meaning, as these EMFs are highly varying any moment due to the reasons described above (and in Panagopoulos et al. 2015b; 2016; Panagopoulos and Karabarbounis 2020). Similarly, accurately calculating the SAR or internal fields within organisms exposed by WC antennas/devices and especially in the near fields is actually impossible and introduces significantly greater errors than measuring the incident fields. While average and peak intensity values can be representatively measured, SAR corresponding values still carry the flaws described above (Sections 1.5.1 and 1.5.2).

For taking into account possible field distortion by the exposed object due to possible resonance phenomena and areas of increased radiation absorption, although such phenomena are not expected to cause any significant alterations, radiation/field intensity measurements should be carried out both in the presence and in absence of the object and in different locations corresponding to different parts of its surface. If the measured values in the presence and in the absence of the object are significantly different, both sets of measurements should be reported.

Certainly, due to the usually encountered non-linearity in the response of living organisms to different environmental stimuli and especially EMFs, not even radiation/field intensity (along with the rest field parameters) is expected to be precise predictor of the expected biological effect at all frequency/intensity areas. Non-linear effects in which the dose-response relation is not a straight line, such as intensity or frequency "windows" reported occasionally in the EMF bioeffects literature (Bawin et al. 1975; 1978; Blackmann et al. 1980; Liboff 2003; Panagopoulos et al. 2010; Panagopoulos and Margaritis 2010b), cannot be predicted by either intensity or SAR dosimetry. At the very least, radiation/field intensity can be readily and more accurately measured than SAR in any case.

As there is today overwhelming evidence on the intense adverse biological activity of man-made EMFs, and especially WC EMFs, with detrimental effects on human/animal health and the natural environment, the need for fast and reliable EMF monitoring has become necessary on a regular basis, especially at residential, social, and working places. EMF measurements should be readily performed by EMF laboratories around the world by proper use of reliable field/radiation meters and spectrum analyzers. Today, such instruments are widely available in the market, relatively cheap, and easily used by qualified and experienced scientists/engineers and trained individuals. EMF dosimetry should not be based on complicated, time-consuming, and largely inaccurate methods of SAR estimation. [The problems with the *SAR* versus incident EMFs were originally analyzed in Panagopoulos et al. 2013b.]

1.6 ALL MAN-MADE EMFs EMIT CONTINUOUS WAVES NOT PHOTONS

1.6.1 Misleading Assessment of EMF Bioactivity Based on Photon Energy

The physics community has accepted that all EMFs (including man-made) and all corresponding types of EMR consist of photons (Alonso and Finn 1967; Beiser 1987; Walleczek 1992; Valberg et al. 1997; Pall 2013; Levitt et al. 2021). According to this postulate, man-made EMFs having frequencies in the subinfrared range ($0–3 \times 10^{11}$ Hz) cannot induce any biological effects because their "photon energies" (according to Planck's law – Eq. 1.3) are lower than those of natural light (Valberg et al. 1997; ICNIRP 1998; 2020; Balzano and Sheppard 2003), which is not harmful at normal intensities but vital. But then, what about the thousands of studies showing a plethora of biological and health effects at man-made frequencies? Is it possible that all these findings corroborating each other are wrong and should be ruled out? The experimental/epidemiological findings are scientific facts and cannot be ruled out. Therefore, obviously, the hypothesis must be ruled out. The hypothesis, here, is that all EMFs (including man-made) consist of photons, and, thus, any effect is due to photon absorption. This hypothesis was not based on experimental facts in the case of man-made EMFs, but on the mathematical "quantization of the EMF" performed by the founders of QED. We shall show here that this hypothesis is flawed in the case of man-made EMFs because spectral data show otherwise, and because the mathematical "quantization" offered by QED/QEM was actually based on the simplistic assumption that all EMFs are periodic in time.

1.6.2 Quantized States Produce Quantized Emissions (Photons) and Line Spectra

There is an intrinsic property of matter that the energy of its elementary particles in a bound state can only take discrete values; in other words, their energy is quantized. It is actually a hypothesis that atoms bound in molecules, electrons bound in atoms, and nucleons bound in nuclei are in perpetual periodic motions at stationary states (discrete energy levels) without emitting radiation, despite their accelerated motion. Radiation is only emitted during transitions from one discrete energy level to another. Such transitions are very fast (of the order of ~ 10^{-9} s for electrons), and, during this time, a wave-packet of certain frequency, phase, polarization, and length (~ 30 cm) is emitted/absorbed (Alexopoulos 1963; 1966; Beiser 1987; Panagopoulos 2015; 2018). These nanosecond wave-packets are the photons. Photons produced by specific transitions (molecular/atomic/nuclear) have discrete frequencies and, thus, give discrete lines in molecular/atomic/nuclear emission spectra. It is well-known in physics that individual sources of quantized emissions (molecules/atoms/nuclei) produce spectra with discrete lines (Herzberg 1944; 1950; Alexopoulos 1963; 1966; Klimov 1975; Burcham and Jobes 1995).

This general hypothesis for the quantization of the electronic energies in all atoms was made by Bohr (1913a; 1913b; 1914; 1928) in the study of the hydrogen atom and was extended by Wilson (1915) and Sommerfeld (1916) for any periodic motion in a single-electron atom. The Bohr-Sommerfeld-Wilson quantization rules allowed the calculation of the stationary energy levels in the hydrogen atom and in single-electron ions, which really corresponded to the observed frequency lines of the atomic spectra. This fact proved correct Bohr's hypothesis for the energy quantization of electrons bound in atoms, and soon it was found that similar quantization rules apply to all bound micro-particles not only in atoms but also in molecules and nuclei (Gautreau and Savin 1978; Beiser 1987).

The energy quantization of all molecules, atoms, and nuclei explains their stability and this, in turn, explains the stability of matter. The quantization implies that bound micro-particles in molecules/atoms/nuclei cannot spontaneously jump from one stationary state to another, as that would require the absorption/emission of energy amounts corresponding to the energy differences between different stationary states. If bound electrons' energies were to take not only discrete values, the electrons would constantly lose energy due to their acceleration around the nuclei (with consequent emission of EMR), and, inevitably, they would collapse and fall on the nuclei. In such a case, no matter would exist in the form of the chemical elements we know (Panagopoulos 2018). A direct consequence of this is that molecules/atoms/nuclei emit and absorb only discrete amounts of energy (photons) corresponding to transitions between discrete energy levels. It was found that the energy differences between such levels in molecules/atoms/nuclei correspond to frequency bands from infrared to gamma rays. More specifically, transitions between different molecular oscillation energy levels correspond to the emission/absorption of photons in the infrared band; electronic transitions in atoms correspond to photons in the visible, ultraviolet; and x-ray bands; and nuclear transitions correspond to photons in the gamma-ray band (Gautreau and Savin 1978; Beiser 1987). Moreover, these quantized transitions correspond to discrete frequencies, and this is why all molecular, atomic, and nuclear spectra are line spectra consisting of discrete lines (Herzberg 1944; 1950; Alexopoulos 1963; 1966).

No transitions were found to correspond to photon energies/frequencies below infrared except for the rare case of photons in the RF/MW band emitted after artificial excitation and/or in the presence of a strong static magnetic field (usually of the order of ~ 0.1–1 T), as in the Stern-Gerlach experiment, in the nuclear magnetic resonance (NMR) spectroscopy, the electron spin resonance (ESR) spectroscopy, and the maser MW amplifiers (see Section 1.6.6). But such strong static magnetic fields do not exist in the environment. The intensity of the terrestrial static magnetic field is ~ 0.5 G = 0.5×10^{-4} T, which is much smaller (~ 2000–20,000 times) than the magnetic field in NMR/ESR spectroscopy (Panagopoulos 2018).

Cosmic MW radiation is known to be of originally higher frequency (infrared/visible) which reaches the Earth reduced due to the Doppler effect taking place because of the cosmic expansion (Durrer 2008; Panagopoulos 2018). Thus, cosmic MWs, indeed, consist of photons, but they are not actually MWs. They are infrared radiation shifted toward lower frequencies. Moreover, they are not polarized or coherent in contrast to man-made MWs which are totally polarized and coherent. Thereby, the argument that living organisms on Earth have always been exposed to MW radiation of cosmic origin does not stand.

In conclusion, all quantized (photonic) emissions occurring spontaneously in our natural and daily environments correspond to discrete frequencies which are, in all cases, higher than the low limit of infrared.

1.6.3 Continuous States Produce Continuous Waves and Continuous Spectra

In contrast to the time-finite emissions from bound micro-particles, free charged particles emit EMR continuously during acceleration, as predicted by classical electromagnetism (Alonso and Finn 1967; Alexopoulos 1973; Jackson 1975). A continuous emission generates continuous waves of length increasing with the duration of the emission. This is fundamentally different from a time-finite quantized emission. It is obvious that such a continuous emission cannot correspond to discrete energy/frequency transitions but to a continuous range of energies/frequencies.

The intensity J of EMR (in the vacuum or in the air) emitted by an accelerating particle of charge q, with non-relativistic velocity (as is the case with free electrons accelerating in the metallic conductors of all electric/electronic circuits/antennas), at any angle θ with the direction of motion, and at distance r from the charged particle, is described by the equation

$$J(\theta) = \frac{q^2 a^2}{16\pi^2 \varepsilon_o c^3 r^2} \cdot \sin^2\theta \qquad [1.38]$$

where α is the acceleration/retardation of the charged particle, ε_o is the vacuum permittivity, and c is the speed of light in the vacuum/air (Alonso and Finn 1967; Panagopoulos 2018).

The frequency range of the emitted radiation is determined by the curves in the free electron trajectories, which, in turn, are determined by the frequency and amplitude of the applied alternating voltage, the electron velocity, and the collision parameters with the ions of the metal. This frequency range extends within a narrow band around the main frequency of the applied voltage (Jackson 1975). When direct (non-alternating) voltages are applied in the circuit, the frequency of the emission is determined by the velocity and the collision parameters only.

Thus, radiation emitted by accelerating/decelerating free electrons in circuits/antennas, or ions and electrons in air discharges, etc., depends upon the square of the acceleration/deceleration α^2. Because the acceleration α can take any possible value (within a range determined by the applied forces), the emitted radiation can also take any possible value within a corresponding range. The emission is not time-finite, and the emitted electromagnetic waves do not consist of discrete wave-packets of finite length but of continuous waves like those described by classical electromagnetism, containing a continuous range of frequencies around the main frequency of the applied voltage in the circuit.

The continuous part of x-ray spectra emitted by retarding free electrons impinging on a metallic surface consists of continuous “classical” waves not photons. Parts of the energy of the continuous waves are absorbed by inner bound electrons in the metal atoms, which get excited to higher energy states, and emit discrete frequencies by de-excitation providing the discrete spectral lines in the final x-ray spectra. The discrete lines correspond to photons, while the continuous part of the spectra corresponds to continuous waves.

Ionic oscillations discovered in all living cells with ULF frequencies of the order of 0.01–0.2 Hz are continuous oscillations and, thus, emit continuous waves not photons. Similarly, atmospheric discharges in the VLF and ELF bands and their resulting Schumann resonances are continuous emissions of accelerating charges (electrons, ions) taking place for as long as the discharge lasts. Finally, all forms of EMR produced by all man-made electric/electronic circuits (e.g., power lines, antennas, etc.) are continuous emissions of accelerating free electrons within the metallic conductors (Panagopoulos 2013; 2018; Panagopoulos and Balmori 2017).

The continuous emission spectra of "black body" radiation, sunlight, light from lamps, hot solid bodies, x-rays, RF/MW antennas, cosmic MWs, and atmospheric discharges are, at least in part, due to accelerating free charged particles such as free electrons/ions (and even neutral molecules in thermal motion) existing in all the above EMR sources and not exclusively to quantized transitions (photons).

Any continuous emission spectrum may be attributed either to a) acceleration of unbound charged microparticles such as free electrons/ions accelerated by an applied electric field and uncharged particles in thermal motion, or b) to transitions of bound microparticles corresponding to a continuous range of photon frequencies, resulting in a seemingly continuous spectrum that even a spectrum analyzer with the highest resolution cannot discriminate the individual spectral lines; or c) to a combination of both a and b cases.

One could, undoubtedly, clarify whether a certain continuous emission spectrum is due to accelerating free microparticles or quantized transitions (photons) of a continuous frequency range were it, indeed, possible to detect discrete photons from the emission source, but it is not. Single photons have not been detected, in spite of opposite claims. In fact, what are really detected are "clicks" in photomultipliers (detectors). Each "click" represents the emission of a discrete photoelectron, and this is interpreted as corresponding to the absorption of a discrete photon (Roychoudhuri and Tirfessa 2008). But highly accurate photon counting experiments have more recently shown that actually the simultaneous detection of multiple photons ("multiple units of $h\nu$") is necessary for the emission of a single photoelectron, and, thus, the production of a single "click" on a detector does not correspond to the detection of a single photon (Panarella 2008). Thus, in reality, single photons have not been detected, in spite of the widely spread impression for the opposite (Roychoudhuri et al. 2008; Roychoudhuri 2014). Since photoelectron emission could also, hypothetically, be triggered by partial absorption of a (divisible) continuous wave, there is no way to verify beyond any doubt the existence of photons by use of photomultipliers.

Therefore, we cannot undoubtedly verify the existence of photons in the continuous spectra, and it is actually only the line spectra that show the existence of photons with discrete frequencies emitted by bound microparticles. As for the continuous spectra of free electron emissions in all man-made EMFs, similarly, there is no proof nor any indication that they consist of photons.

A single charged free microparticle accelerating in the vacuum due to an alternating applied voltage may move periodically, and then its emission spectrum would (theoretically) contain only discrete lines/frequencies. But in electric/electronic circuits, we do not have a single microparticle accelerating in the vacuum due to a perfectly alternating applied voltage. Instead, we have innumerable microparticles (free electrons) moving not periodically (even in case of a perfectly alternating field), with each one's individual period/frequency slightly differing from all others' due to the chaotic friction forces which are different for each individual microparticle, plus their random thermal motion, which is also different for each one. This is why EMR produced by accelerating free charged microparticles gives continuous emission spectra and why all antennae spectra are continuous spectra (Panagopoulos 2018).

In conclusion, bound charged microparticles produce photons with discrete frequencies/energies and line spectra, while free charged microparticles produce continuous waves and continuous spectra. This distinction is fundamental for understanding the arguments presented here.

1.6.4 How Causality Was Abandoned in Modern Quantum Physics

According to the Fourier theory, all periodic motions of any frequency can be represented as a sum of discrete harmonic oscillations with a basic frequency ν and its harmonic frequencies 2ν, 3ν, …, etc. Non-periodic functions/motions may also be developed into Fourier series, but, in this case, the Fourier series do not approach the initial functions. One of the three Dirichlet conditions in order for a Fourier series to approach the initial function is that the initial function must be periodic. Therefore, non-periodic undulations cannot be represented as a sum of discrete harmonic terms. Except for the Fourier series, any continuous and integrable function, periodic or not, can be transformed by the Fourier integral/transform into another continuous function consisting of infinite number of (non-discrete) harmonic terms (Stephenson 1973; Spiegel 1974; Panagopoulos 2018). But a continuous function with no discrete terms cannot be considered as "quantized". It is most strange that these simple facts were overlooked by the founders of QEM/QED and their successors. Let us see briefly how this happened.

De Broglie (1924) ascribed a wavelength (λ) on elementary particles. such as electrons, accepting that they possess a wave-like nature and called these waves "matter-waves":

$$\lambda = \frac{h}{mu} \quad \text{or} \quad k = \frac{p}{\hbar} \qquad [1.39]$$

(m, u, and p are the particle's mass, velocity, and momentum, respectively, and k is the wave number). His hypothesis was soon confirmed experimentally when it was shown that electrons produce diffraction patterns just like x-rays (Davisson and Germer 1927).

In his attempt to find an equation to describe the energy of the electronic "matter-waves" in the many-electron atoms, Schroedinger (1926) took the classical wave-function,

$$\xi(r,t) = e^{i(\omega t - kr)} \qquad [1.40]$$

which describes a plane harmonic wave of circular frequency $\omega = 2\pi\nu$ (ν the frequency) and wave number $k = 2\pi/\lambda$ (λ the wavelength) at distance r from its source along the direction of propagation [i is the imaginary unit ($i^2 = -1$)] (Alonso and Finn 1967). [The fact that Eq. 1.40 describes a plane harmonic wave comes from the Euler formula, $e^{i\theta} = cos\theta + isin\theta$ (Stephenson 1973), with the convention that physical quantities are obtained by taking the real parts of complex quantities (Jackson 1975). Thus, a physical wave described by Eq. 1.40 depends solely upon $cos(\omega t\text{-}kr)$ (which is a harmonic function of time) and, therefore, it is a plane harmonic wave.]

Then he substituted ω and k by their corresponding quantum mechanical expressions (derived directly from Planck's and De Broglie's Eqs. 1.3 and 1.39, respectively, $\omega = \in/\hbar$ and $k = p/\hbar$) and derived what he called the quantum mechanical "wave-function" in direct analogy with the classical wave-function (Schroedinger 1926; Tarasov 1980; Trachanas 1981):

$$\psi(r,t) = e^{i(\in t - pr)/\hbar} \qquad [1.41]$$

The square of the wave-function ψ^2 supposedly describes the probability for the electron to be found at distance r from the nucleus at a given time. That was arbitrarily accepted also in analogy with classical wave physics in which the square of the oscillating quantity (wave-function) is proportional to the energy density of the wave. Thus, Schroedinger identified the energy density of the matter wave associated with the electron at a specific location around the nucleus, as the probability of finding the electron at this location (Panagopoulos 2018).

Differentiating Eq. 1.41 with respect to r and t, he found the operator $-i\hbar(\partial/\partial r)$ corresponding to the momentum and the operator $i\hbar(\partial/\partial t)$ corresponding to the energy of the particle, respectively.

In classical physics, the total (conserved) energy value $\in$ of a particle with mass m and momentum p moving with potential energy $V(r)$ is the sum of its kinetic and potential energy. The equation $\in = p^2/2m + V(r)$ expresses the energy conservation law.

Since the wave-function $\psi(r, t)$ was introduced to represent the wave associated with the particle under study, Schroedinger demanded *a priori* that it must satisfy the equation:

$$\in \psi = \left(\frac{p^2}{2m}\right)\psi + V(r)\psi \qquad [1.42]$$

Substituting in the last equation the energy and momentum by their corresponding operators, we get:

$$i\hbar\left(\frac{\partial\psi}{\partial t}\right) = -\left(\frac{\hbar^2}{2m}\right)\left(\frac{\partial^2\psi}{\partial r^2}\right) + V(r)\psi \qquad [1.43]$$

In three dimensions, the equation, describing the energy conservation law for a "matter-wave", becomes:

$$i\hbar\frac{\partial\psi}{\partial t} = -\frac{\hbar^2}{2m}\nabla^2\psi + V(r)\psi \qquad [1.44]$$

($\nabla^2 = \frac{\partial^2}{\partial x^2} + \frac{\partial^2}{\partial y^2} + \frac{\partial^2}{\partial z^2}$ is the Laplace operator)

Despite the arbitrary assumptions made by Schroedinger in order to derive his equation (Eq. 1.44), there was a causal reasoning in his methodology up to this point, and this is probably the reason why this equation seems to really work in describing the electronic states in atoms. But causality was abandoned in the next step.

Although the Schroedinger equation was originally written to describe the energy of electrons bound in atoms, since they were described by harmonic wave functions with quantized energy, it was arbitrarily extrapolated for the case of a free electron/particle with zero potential energy [$V(r) = 0$] when it was also written by Schroedinger himself as,

$$i\hbar\frac{\partial\psi}{\partial t} = -\frac{\hbar^2}{2m}\nabla^2\psi \qquad [1.45]$$

But in such a case, how can a harmonic wave-function (Eq. 1.41) with quantized energy be attributed to a free particle? By doing this, it was automatically accepted that any free particle can only have discrete energy values by itself, even when it is not in periodic motion. That was an unphysical extrapolation, and the start of a wrong direction that was to be followed. Causality was ruined by this step.

This unphysical extrapolation made by Schroedinger (1926) was blindly followed by Klein, Gordon, Dirac, Heisenberg, and everybody else at that time, when they all adopted this equation to describe a free particle (!), and this was surprisingly accepted by everyone else in the quantum physics community until today without any objections (Panagopoulos 2018).

1.6.5 The Mathematical "Quantization" of EMF/EMR

The reasoning of "quantization" of an EMF/EMR is described by Dirac (1927): "Resolving the radiation into its Fourier components, we can consider the energy and phase of each of the components to be dynamical variables describing the radiation field". But according to the Fourier theory, a non-periodic function (such as any random emission of radiation) cannot be represented/approached by Fourier components.

Let us see in brief how Heisenberg, Born, Jordan, Pauli, and Dirac "quantized" the EMF/EMR, starting from its classical description by Maxwell's equations. In the vacuum or the air and considering the free fields (without electric charges or currents), Maxwell's equations (Alonso and Finn 1967) are written as:

$$\nabla \cdot E = 0 \quad [1.46]$$

$$\nabla \cdot B = 0 \quad [1.47]$$

$$\nabla \times E = -\frac{\vartheta B}{\vartheta t} \quad [1.48]$$

$$\nabla \times B = \varepsilon_o \mu_o \frac{\partial E}{\partial t} \quad [1.49]$$

They introduced a vector potential $A(r, t)$ which should, *a priori*, satisfy both the constraint $\nabla{\cdot}A = 0$ and the equations:

$$B = \nabla \times A \quad [1.50]$$

$$E = -\frac{\vartheta A}{\vartheta t} \quad [1.51]$$

[vector labeling (→) on E, B, A, is omitted for simplicity]

After such a fabrication, substituting Eqs. 1.50 and 1.51 into Eq. 1.49, it comes that $A(r, t)$ satisfies the classical wave equation (to be transmitted along the direction r with velocity c, just like the electric and magnetic components of an electromagnetic undulation):

$$\frac{\partial^2 A(r,t)}{\partial t^2} = c^2 \nabla^2 A(r,t) \quad [1.52]$$

with $c = \frac{1}{\sqrt{\varepsilon_o \mu_o}}$ the velocity of the electromagnetic wave.

Then they demanded the vector potential to be a periodic function of time and separated it into a sum of two conjugate complex terms:

$$A(r,t) = A^{(+)}(r,t) + A^{(-)}(r,t) \quad [1.53]$$

where $A^{(+)}(r, t)$ contains all amplitudes which vary as $e^{-i\omega t}$ for $\omega > 0$, and $A^{(-)}(r, t)$ contains all amplitudes which vary as $e^{i\omega t}$, and $A^{(-)} = A^{(+)*}$. Thus, they fabricated $A(r, t)$ in such a way that a) satisfies the wave equation and b) is a periodic function of time and, thus, contains only harmonically varying terms.

Since they accepted that $A(r, t)$ is periodic in time, they developed its terms into Fourier series of harmonic terms, according to the Fourier theorem, with a set of vector "mode" functions $u_k(r)$ satisfying the wave equation, $(\nabla^2 + \omega_k^2/c^2)\, u_k(r) = 0$ for harmonic waves, corresponding to the frequencies ω_k, describing the field restricted in a volume V in space (with c_k the Fourier coefficients):

$$A^{(+)}(r,t)=\sum_k c_k u_k(r)e^{-i\omega_k t} \qquad [1.54]$$

Finally, after additional arbitrary requirements and operations, the vector potential is transformed as:

$$A(r,t)=\sum_k \left(\hbar/2\omega_k\varepsilon_o\right)^{1/2}\left[a_k u_k(r)e^{-i\omega_k t}+a_k^{\dagger}u_k^{*}(r)e^{i\omega_k t}\right] \qquad [1.55]$$

The Fourier amplitudes a_k, and $a_k^{\dagger}$, were arbitrarily chosen to mutually adjoint operators which satisfy the commutation relations: $[a_k, a_{k'}] = [a_k^{\dagger}, a_{k'}^{\dagger}] = 0$, $[a_k, a_{k'}^{\dagger}] = \delta_{kk'}$
$[\delta_{kk'} = 1$ for $k = k'$, and 0 for $k \neq k'$ (the "Kronecker's delta" function)]

Replacing $A(r, t)$ into Eq. 1.51, the electric field becomes:

$$E(r,t)=i\sum_k \left(\hbar\omega_k/2\varepsilon_o\right)^{1/2}\left[a_k u_k(r)e^{-i\omega_k t}-a_k^{\dagger}u_k^{*}(r)e^{i\omega_k t}\right] \qquad [1.56]$$

and a similar expression is found for the magnetic field. These finally transform the Hamiltonian (total energy) of the EMF as:

$$H=\sum_k \hbar\omega_k\left(a_k^{\dagger}a_k+\frac{1}{2}\right) \qquad [1.57]$$

[For details see Mandel and Wolf (1995), Walls and Milburn (2008), and Panagopoulos (2018)]

Eq. 1.57 represents the total energy of the EMF as the sum of the number of photons in each mode $a_k^{\dagger}a_k$, multiplied by the photon energy in this mode $\hbar\omega_k$, plus $\frac{1}{2}\hbar\omega_k$ representing the energy of the "vacuum fluctuations" in each mode.

Thus, the famous "EMF quantization" is nothing more than mathematically transforming a periodic EMF into a sum of discrete terms by use of the Fourier series. But in nature, most forms of EMFs are not periodic and cannot be approximated as such. Finally, the fact that they mathematically transformed a periodic EMF into a sum of discrete terms does not mean that these terms represent photons. There should be facts supporting this "quantization", and such facts do not exist for man-made EMFs or for the other EMF continuous emissions with frequencies below infrared described above (see Section 1.6.3).

1.6.6 No Evidence of Photons at Frequencies below Infrared in Environmental Conditions

Let us now examine what are referred to as "microwave photons" and the ways they are generated (originally discussed in Panagopoulos 2018). As for lower frequency bands (lower RF, LF, VLF, ELF, ULF), there is not even a mention in the physics literature regarding actual evidence of photon existence.

MW Generators

MWs are produced artificially by generators such as the magnetron, the klystron, and the masers (Lioliousis 1979). The magnetron and the klystron produce electron beams emitted by a cathode and directed to pass through a series of positively charged metal cavities called "cavity resonators". The frequency of the produced oscillations in the electron beam is determined by the cavities' dimensions and the beam's speed. Such MW generators are used in radars and in MW ovens. The produced MWs last for as long as the electrons accelerate within the cavities and are, thus, continuous/uninterrupted waves. They are produced by unbound electrons accelerated by an applied voltage just like in every electric/electronic circuit, and there is no reason to assume that they are quantized. There are no time-finite emissions to correspond to quanta (photons).

In the case of masers (microwave amplification by stimulated emission of radiation), the continuous MWs produced by a klystron or magnetron are amplified by MW photons produced by some paramagnetic material, such as NH_3 or crystals such as silicon (Si), after excitation by the continuous MWs and in the presence of a strong static and spatially inhomogeneous magnetic field with intensity of the order of ~ 1T, like in the Stern-Gerlach experiment. This, indeed, describes conditions of photon production in the RF/MW band. It is related to the splitting of spin energy levels of uncoupled electrons or nucleons within a strong static magnetic field B (~ 1T) (Gautreau and Savin 1978), which is the underlying effect in the ESR and NMR spectroscopies. Uncoupled particles may jump between the two separated spin levels with corresponding emission/absorption of photons in the MW band. Thus, such photons may exist under the specific conditions.

But such strong static magnetic fields (~ 1T) do not exist in human environments. Moreover, the production of MW photons cannot take place without excitation by the artificial (continuous) MWs. Thus, we do not expect to have MW photons due to this mechanism in environmental conditions.

Atomic Transitions in the RF/MW Band

There are atomic transitions due to the hyperfine splitting of electronic energy levels in atoms, corresponding to photon energy in the RF/MW band (typically of a few GHz). The hyperfine splitting is due to the interaction of the nuclear magnetic moment with the electron magnetic moment. The function of "atomic clocks" is based on this effect. Such hyperfine transitions do not occur naturally/spontaneously and need to be excited artificially. In atomic clocks, excitation of cesium atoms is achieved by periodic laser signals in a chamber at superconductive conditions (extremely low temperature very close to absolute zero, -273°C). By de-excitation, the cesium atoms emit photons of precise MW frequency. Other ways to excite MW transitions in atoms involve magnetic resonance by an externally applied magnetic field (of the order of ~ 0.1–1 T) and artificial MW radiation (see above). The resulting magnetic resonance is observed by changing the frequency and magnitude of the applied RF field. Again, such conditions do not exist environmentally, and the described hyperfine transitions do not occur naturally (Major 2014; Kraus et al. 2014; Panagopoulos 2018).

MWs Produced by "Qubits"

In practice, the devices that are currently being developed to produce MW "photons" need to be operated at temperatures below 0.1K (or -272.9°C) (Houck et al. 2007; Inomata et al. 2016). Until recently, this would have meant using cryostats with liquid helium for cooling, which is generally not possible in conditions outside of research labs. Rapid progress in cryogenics has already produced dry mechanical systems that only require a source of electricity to operate (Radebaugh 2009), but still, such conditions do not exist environmentally.

Recent claims that MW/RF photons can be generated in electronic circuits also involve superconductive/cryogenic conditions. The so-called "microwave photons", generated by special MW oscillation circuits, called quantum bits ("qubits"), are manifested as electromagnetic pulses. Qubits are integrated micro-circuits made by lithography and containing capacitors (C) and inductors/coils (L) forming LC harmonic oscillators. They are the basic units of the so-called "quantum computers" (Houck et al. 2007). A large amplitude trigger pulse generated by a conventional MW pulse generator in the "in" port excites the qubit which, a few tens of nanoseconds later, decays into the "out" port by emitting a second pulse which is interpreted as a MW "photon". With the circuit resistance approaching to zero in superconductive conditions, the generated pulses (interpreted as "photons") are practically harmonic (Houck et al. 2007; Schuster et al. 2007; Clarke and Wilhelm 2008).

Thus, the so-called MW "photons" emitted by qubits are not quantized transitions of bound micro-particles but pulses of a continuous carrier wave at MW frequency produced by the LC artificial micro-circuits. Even if we interpreted these artificial MW pulses as photons, which is definitely not the case, they could not exist in the environment (without superconductive/cryogenic conditions and without artificial excitation) (Panagopoulos 2018).

In conclusion, all present day "quantum" MW emitters a) need to be triggered by artificial pulses and b) are cooled down to extremely low temperatures (Houck et al. 2007; Kraus et al. 2014).

Antennae Spectra

If man-made EMR types were indeed quantized, according to QEM/QED hypothesis, then all antennae emission spectra anywhere in the whole band below infrared (0–3 × 10^{11} Hz) would be line spectra consisting of discrete lines corresponding to the basic carrier frequency emitted by the antenna and its harmonics plus the modulation frequencies. Although spectra may be very complicated, and discrete lines may broaden due to a variety of reasons, as is usually the case in molecular, x-ray, and gamma-ray spectra, acquiring these spectra with increased resolution reveals their discrete lines. In contrast, all antennae emission spectra do not display discrete lines regardless of resolution, but they do display continuous frequency bands around the main emission frequencies. This is because, even though macroscopically the free electron cloud in the antenna circuit may perform a periodic motion at a certain carrier frequency ν, the motion of each individual free electron is not periodic due to the chaotic friction forces which are different for each individual free electron plus the individual random thermal motion, as explained. The result is that, instead of an individual emitted frequency, we have a continuous range of frequencies $\pm\Delta\nu$ around the carrier frequency ν of the alternating voltage applied on the antenna circuit. In other words, instead of single lines, we have continuous frequency bands with peaks on the main frequencies (Panagopoulos 2018).

Thus, antennae spectra are continuous spectra, even though antennas in most (almost all) cases emit a periodic carrier signal, and this is an additional indication that all man-made EMR types do not consist of photons but of continuous waves.

In conclusion, there is actually no evidence showing photon existence at frequencies below infrared, in environmental conditions, or showing that man-made MW radiation types transmitted by WC antennas/devices, radars, satellites, etc., consist of photons.

1.7 DIFFERENCES FROM NATURAL EMFs. INTERACTION WITH MATTER

1.7.1 Differences between Natural and Man-made EMFs/EMR

Many people, including scientists, are not aware of the differences in the physical properties and the consequent differences in biological activity between natural and man-made EMFs/EMR, coming to the erroneous conclusion that since natural light, which is of significantly higher intensity and frequency, does not induce adverse health effects, man-made EMFs/EMR should not induce adverse effects either. Let us summarize the differences between natural and man-made EMFs/EMR which were analyzed in the previous sections (and originally in Panagopoulos 2018).

A. *Polarization*: All man-made EMFs/EMR emitted by circuits/antennas are totally polarized (and coherent), in most cases linearly polarized, oscillating on a certain plane determined by the orientation/geometry of the antenna/circuit. By contrast, natural EMFs/EMR (such as Schumann resonances, cosmic MW, infrared, visible, ultraviolet, gamma) are never totally polarized (nor coherent) and may only be partially polarized in a small degree under certain conditions. Exceptions are the geomagnetic and geoelectric fields and the cell membrane electric fields, which are locally polarized but static.
B. *Frequency bands*: Man-made EMFs/EMR occupy the lower frequency bands, from 0 Hz up to the low limit of infrared (~ 3 × 10^{11} Hz). Natural EMFs/EMR occupy the higher frequency

bands of the electromagnetic spectrum, from infrared to gamma rays (3×10^{11}–3×10^{22} Hz). Exceptions include a) the VLF/ELF EMFs of atmospheric discharges (lightning) and consequent Schumann resonances; b) the geoelectric, geomagnetic, and cell membrane electric fields which are basically static with ELF variations (Presman 1977; Dubrov 1978; Panagopoulos 2013; Panagopoulos and Balmori 2017); c) the preseismic ULF/ELF/VLF pulsations (including SES) recorded a few days or weeks before major earthquakes (Panagopoulos et al. 2020); and d) the ULF ionic oscillations in all living cells.

C. *Bound versus unbound emission sources*: Natural EMR is produced by time-finite transitions (excitations/de-excitations) of bound charged microparticles (i.e., atoms/ions, electrons, or nucleons, in molecules, atoms and nuclei respectively), between quantized energy levels, and for this reason it consists of time-finite wave-packets (photons). By contrast, man-made EMR types (and the above-mentioned exceptions of the atmospheric/terrestrial/biological natural ULF/ELF/VLF EMFs), are produced by continuous (uninterrupted) acceleration of free electrons/ions due to an applied EMF, and for this reason they consist of continuous "classical" waves.

The above fundamental differences indicate that man-made EMFs should not be confused or compared with the natural ones without addressing these differences, and they should not be evaluated for their biological activity by the same criteria (Panagopoulos and Margaritis 2003; Panagopoulos 2011; 2013; 2018).

1.7.2 Basic Concepts of Interaction of EMFs/EMR with Matter

Natural EMR (from infrared to gamma) passing through inanimate matter can be absorbed by bound charged atoms/ions in molecules (infrared), electrons in atoms (visible, ultraviolet, x), or nucleons in nuclei (gamma) in all materials and by free electrons in metals. The main mechanisms of interaction are:

A. *Excitations*: They take place when the frequency of the radiation is close to the frequencies of the molecular/atomic/nuclear spectra in the corresponding bands. Bound charged atoms and electrons absorb the necessary amount of energy in order to jump to a higher stationary energy level. The excited molecules/atoms/nuclei are unstable, re-emit the absorbed energy in the form of time-finite emissions (photons) in random directions, and get back to their initial energy levels.

B. *Ionizations*: For higher frequencies (vacuum ultraviolet, x-rays, gamma rays) the absorbed energy is adequate to ionize the atoms by expelling electrons and even excite or break nuclei (in the case of gamma radiation). These are known effects of ionizing radiations (Alexopoulos 1963; Klimov 1975; Gautreau and Savin 1978; Beiser 1987; Burcham and Jobes 1995).

C. *Forced oscillations*: Bound charged atoms and electrons in all materials and free electrons in metals are forced to oscillate at the frequency of the radiation in addition to their initial motions. The energy of the forced oscillation is subtracted from the radiation and re-emitted by the charged particles in all directions. This causes scattering of the initial waves (Alonso and Finn 1967; Alexopoulos 1963; Klimov 1975; Panagopoulos 2018). In all cases, the initial EMR is left with the same frequency but reduced intensity.

Man-made EMR has several orders of magnitude lower frequency than the frequencies of the molecular/atomic/nuclear spectra (ranging from the infrared to the gamma-ray band), and thus, it is not expected to induce excitations or forced oscillations on bound microparticles and certainly not ionizations.

Forced-oscillation of free electron clouds on metallic surfaces is the mechanism by which metals absorb man-made EMFs/EMR. In this case, the absorption is so intense as to practically eliminate EMR in the interior of the metallic object and shield other objects behind the metallic surface (e.g., "Faraday cage"). This is how metals can insulate space from EMFs/EMR (Alexopoulos 1973; Panagopoulos 2018; Panagopoulos and Chrousos 2019).

The situation is different when the continuous polarized waves of man-made EMFs/EMR pass through living tissue. Living tissue consists of biological cells, and in all types of cells (and in the extracellular fluids), except for the bound electrons in atoms/molecules, there are trillions of mobile ions, water polar molecules, and polar macromolecules. The vast majority of biological molecules such as proteins, lipids, nucleic acids, etc., are either polar or carry a net electric charge (Alberts et al. 1994; Stryer 1996). Therefore, except for the above mechanisms of energy loss on bound electrons, there are induced forced oscillations on every charged or polar molecule of the biological tissue (as described in Section 1.4). These forced oscillations of ions and polar (macro)molecules absorb much more energy than the induced oscillations on the bound electrons of the biological molecules because the masses of the charged/polar particles are now several orders of magnitude (more than 10^4 times) bigger. The forced oscillations induced by man-made EMFs/EMR in biological tissue are parallel and coherent oscillations since, as explained, these fields are totally polarized and coherent.

The induced oscillations will be most intense on the mobile ions which carry a net electric charge and have smaller mass and higher mobility than other charged or polar molecules (Alberts et al. 1994; Panagopoulos 2013). The induced oscillations will be much smaller or even negligible on the polar macromolecules that do not carry a net electric charge, they have much greater masses, and they are usually chemically bound to other molecules. Forced oscillations of mobile ions can trigger biological effects (Panagopoulos et al. 2000; 2002; 2015; 2020; 2021).

After induction of forced oscillations by the continuous polarized waves on the charged/polar molecules of living tissue and consequent abstraction of energy from the initial wave, the remaining wave continues its way through the tissue with the same frequency but reduced amplitude/intensity. After countless numbers of such events, depending on the tissue's mass, density, and the number of polar/charged molecules, any remaining wave leaves the tissue scattered and with reduced amplitude/intensity (Panagopoulos et al. 2013b).

The wave intensity J (as in the simplest case of a plane harmonic electromagnetic wave described by Eq. 1.7) decreases with decreasing amplitude/intensity E of the oscillating field/wave within the tissue after interaction with the charged/polar molecules. Thus, the amplitude and energy of each individual continuous wave decrease.

The energy loss of the man-made electromagnetic waves may be manifested as heating of the exposed material (e.g., MW heating) without any frequency reduction as, e.g., in the Compton effect. Information-carrying MWs do not change their frequency when passing through matter, but they can cause heating when they have sufficient intensity and frequency (MWs in the GHz range with intensity ≥ 0.1 mW/cm^2).

Thus, man-made EMF/EMR types lose energy not by losing a number of photons absorbed by the medium or by decreasing their frequency as in the Compton effect (by getting absorbed and giving rise to scattered photons of decreased frequency). This might explain why MW radiation can cause greater temperature increases than ionizing radiation when absorbed by matter, although it has considerably lower frequency. Ionizing radiation is quantized (photonic) and described by Planck's equation (Eq. 1.3) in terms of its energy, while man-made radiation (including MWs) consists of continuous waves, and described by Eq. 1.7, in which the energy loss is not dependent on quantized (all or nothing) absorption but on partial absorption from a continuous/uninterrupted wave, inducing a continuous forced oscillation on charged/polar particles. In this case, the energy loss transformed into heat may be greater, even though the frequency is several orders of magnitude smaller.

Natural non-ionizing quantized EMR (infrared, visible light) also decreases in intensity (number of photons) when passing through biological matter by causing forced oscillations on charged/polar particles. But these oscillations are in random directions (each photon oscillates on a different plane) and not coherent. For this reason, they only cause heating (increase in molecular random thermal motion) which is tolerated by living organisms if it is not excessive. Important adverse biological effects and cancer may be caused by (natural quantized) ionizing radiations through the breakage of chemical bonds in biological molecules. Thus, the mechanisms of interaction with living tissue are quite different between quantized and not quantized EMR, even though they may finally result in the same effects (e.g., genetic damage, cell death, cancer, etc.).

1.8 DISCUSSION AND CONCLUSIONS

In this chapter we described the physical properties that characterize WC EMFs. Some of these properties (polarization/coherence, non-thermal energies, and emission of continuous waves instead of photons) account not only for WC EMFs but for all types of man-made EMFs. The combination of polarization/coherence with the intense variability of the WC signals, the combination of different frequency bands, and the ULF/ELF components in the form of pulsing, modulation, and random variability, are specific properties of the WC EMFs. Although WC EMFs are usually referred to in the literature simply as "RF" EMFs, this is not only inaccurate but also misleading, as these fields/radiations necessarily combine RF carrier signals with ELF/VLF modulation and pulsing plus ELF/ULF random variability. These ELF/ULF components are the most bioactive, not the RF carrier, which is usually responsible only for heating.

We explained the property of polarization which (combined with coherence) is inherent in all technical/artificial/man-made EMF/EMR emissions, including those of WC. We showed how this property is necessary for the induction of biological effects through the phenomena of constructive interference and most importantly the induced forced oscillations on every charged particle in biological tissue and especially mobile ions. We showed that the biological effects of man-made EMFs arise from their unique property of being totally polarized (and coherent) capable of inducing parallel and coherent forced oscillations/rotations on charged/polar molecules which are the vast majority of molecules in living tissue.

We underscored that polarization alone is not enough for the induction of biological effects but low frequency (ULF/ELF/VLF) variability of the EMF exposure is also necessary. In a comparison study, 36 min total exposure to real-life GSM (2G) EMF emitted by a mobile phone induced DNA damage in fruit fly ovarian cells in a much higher degree than 120 h total exposure to 50 Hz alternating EMF significantly stronger than those of high-voltage power lines. The crucial difference between the two exposures was found to be the intense variability of the real-life GSM EMF (Panagopoulos 2019a). The importance of field variability, especially in intensity, is also indicated by the recorded health effects in human populations during magnetic storms, the nerve impulses which are voltage changes in the membranes of nerve cells, and the gating of VGICs in all cell membranes. These effects do not occur while the static polarized terrestrial or cell membrane fields retain their regular field intensities but initiate once their intensities undergo changes of the order of 20%–30% of their regular values. This bioactive variability lies mainly in the ELF/ULF band. In addition, a plethora of experimental findings show the increased ability of ELF/ULF man-made (polarized) EMFs to induce biological effects.

We noted the similarity between the terrestrial fields and the cell membrane fields. They are both locally polarized and static and normally not bioactive. Effects are triggered whenever changes of ~ 20%–30% of their regular field intensities occur. This observation is important for the explanation of the biological/health effects of EMFs in general and shows that polarization, combined with variability, is the trigger for EMF bioeffects (Panagopoulos 2019a).

We explained that all WC EMFs necessarily contain ULF/ELF/VLF components in the form of modulation, pulsing, and random variability, and thus, they combine polarization with ELF/ULF variations. Although information regarding the ELF pulsations of WC EMFs (especially of LTE, 5G, and Wi-Fi) is limited in the literature and not easily accessible for reasons unknown to us, we provided measurements of the ELF components (Table 1.1), and we showed pulsations of the most common forms of such emissions, such as GSM (2G MT), UMTS (3G/4G MT), LTE (4G), DECT, and Wi-Fi/Bluetooth, (Figures 1.2–1.8) collected from the available specialized studies on this topic. The difficulty in finding information in the literature regarding the ELF pulsations of WC EMFs (summarized in Table 1.2), in spite of the fact that the pulsing character of these EMFs/radiations is their most important technical feature and their most bioactive component, shows the degree of misinformation prevailing today in science.

In a recent review of studies of the European Parliamentary Research Service (EPRS 2021) (authored by Thielens and reviewed by Vacha and Vian) regarding environmental impacts of 5G, there is no mention of pulsations or any other ELF components, and the only examined frequency band of the radiation is the carrier (MW) frequency. Moreover, the importance of the inherent variability of the real WC exposures in inducing biological/health effects is not even mentioned, and studies are criticized for having used real-life emissions from mobile phones for the exposures, which, as explained, is the only realistic exposure method (Panagopoulos et al. 2015b; 2016; Panagopoulos 2017; 2019a; Leach et al. 2018; Kostoff et al. 2020). Thus, the most important parameters of WC EMFs (low frequency components, variability) were completely ignored. They criticized the real-life exposures and the EMF measurements in our and others' studies, based on Verschaeve (2014) and do not mention our published comments on Verschaeve's paper (Panagopoulos et al. 2016). Reproducing the criticism expressed in a paper without referring to the peer-reviewed published response to this criticism is a major flaw. Verschaeve is known for attempting to discredit every study that has found effects from man-made EMFs. His "arguments" collapsed in our comments (Panagopoulos et al. 2016). As a result, he did not comment on our studies again (Verschaeve 2017). Now EPRS (2021) reproduce Verschaeve's (2014) "arguments" as if they were not rebutted. This is not a way for science to move forward.

Another recent review of 107 experimental and 31 epidemiological studies with "RF" EMFs above 6 GHz (in order to assess bioactivity of 5G) by members of the Australian Radiation Protection and Nuclear Safety Agency again makes no mention of pulsations or any other ELF components in the 5G or in the examined studies, and no mention whether there is any similarity of the signals produced by generators in the studies with those of the 5G apart from the carrier frequency. Although most of the reviewed studies had reported genotoxic and various other effects, the authors of the review found "no confirmed evidence" of adverse effects on human health and criticized the studies for not being "independently replicated" and for employing "low quality methods of exposure assessment and control" (Karipidis et al. 2021). The same authors also made a "meta-analysis" of the same 107 experimental studies and found that the studies "do not confirm an association between low-level mm-waves and biological effects" (Wood et al. 2021). They also estimated the "effect size" (an arbitrary measure of bioactivity) among studies that reported "continuous wave" and "modulated" "RF" EMFs and found "non-significant difference". But the "effect size" of the studies reporting modulation was found to be almost double (4.3 ± 1.6) than that of the studies reporting "continuous wave" (2.2 ± 0.6), and it is strange how this difference was reported as "non-significant". Moreover, as explained in the present chapter and in Panagopoulos (2021), it is unlikely that any MW generator does not contain on/off pulsations, even only for energy-saving reasons, as in radars. Even the onset and removal of an EMF exposure alone may produce the greatest effects (Goodman et al. 1995).

The fact that these two publications and the EPRS (2021) ignore the presence of ELF components and whether the reviewed studies employed simulated signals or real-life WC signals, shows that they are not reliable for investigating the health issues of these types of EMFs. Such publications attempt to present 5G radiation as harmless to health and environment, which is clearly not the case.

A part of the scientific community believes that the ELF/ULF components of WC EMFs do not exist independently of the RF carrier and need to be "demodulated" in order to affect living organisms (Goldsworthy 2006; Sheppard et al. 2008; Wust et al. 2021). Demodulation of a modulated RF signal is accomplished by "non-linear" electronic elements in the RF receivers in electronics, such as diodes, transistors, etc. (Alexopoulos 1973; Schwartz 1990). Studies have clearly shown that the

ELF elements exist and can be recorded independently of the RF carrier, as shown in Section 1.3.2 (Pedersen 1997; Holma and Toskala 2004; Zhou et al. 2010; Pirard and Vatovez). "Demodulated" or not, the fact is that both ELF meters and living organisms detect them and are affected by them. This is why modulated and pulsed RF EMFs by ELF are shown by plethora of studies (cited in the Introduction of this chapter) to be bioactive, while the corresponding non-modulated and non-pulsed signals are not.

We analyzed the physics of non-thermal effects of man-made EMFs in biological tissue, which constitute the vast majority of effects at environmental conditions and the physics of thermal effects (the known phenomenon of MW heating). We calculated the velocity of an ion passing through an open channel in a cell membrane (Eq. 1.27), which represents an upper limit for any velocity of a mobile ion in living tissue under the influence of an applied EMF. This velocity is of major importance for the estimation of physical effects in living cells (see also Chapter 11) and represents a biophysical constant. We calculated the corresponding maximum kinetic energy and compared it with the average thermal energy of the same particle. We showed that this upper limit energy of an ion is millions of times smaller than the average thermal energy of the same particle, and this explains why the vast majority of the recorded biological/health effects of man-made EMF exposures are non-thermal. The available evidence shows that these non-thermal effects are due to the ELF EMFs included in almost all artificial EMFs in combination with their totally polarized and coherent character.

In recent publications, Wust et al. (2020; 2021) (Table 1.1 in both papers) provide ion velocities though opened channels about four orders of magnitude smaller (~ 10,000 times). They estimated these as being due to an applied RF field supposedly "rectified" by the membrane and superimposed to the transmembrane field. But how can an externally applied field be rectified by a cell membrane? Ions (both positive and negative) flow in and out of the membrane through the channels all the time. If the membranes were "rectifiers", they would only allow ion flows in one direction. They "estimated" this "rectified" voltage to be of the order of 1 μV while the transmembrane voltage is ~ 100 mV. This is completely hypothetical and not based on measurements (in contrast to Eq. 1.27). Moreover, it can be very misleading, as readers may think that the ion velocities through open channels may be of such magnitude.

Recently, due to the higher MW frequencies ("mm-waves") included in 5G, certain Russian studies came to light reporting "non-thermal effects of MW/mm-wave EMFs". Three reviews of such studies in English are Pakhomov et al. (1998), Betskii and Lebedeva (2004), and Belyaev (2005). In several studies reviewed in Pakhomov et al. (1998), and in Belyaev (2005), ULF/ELF, and VLF components were reported to be present in the form of pulsing, and/or modulation/intermittence/variability, while for the rest of the reviewed studies, no information on possible existence of such components was provided, and thus, their presence is not excluded. In the Betskii and Lebedeva (2004) review paper, information on the possible existence of low frequency components (ULF/ELF/VLF) is totally missing throughout the paper, and thus, their presence is again not excluded. Since, as explained, it is unlikely that any MW 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 investigated in order to prevent misleading conclusions. In this context, speaking of "non-thermal MW effects" without having clarified whether these effects are indeed due to the MWs or to their low frequency components can be very misleading. Systematic attempts by Gandhi and coworkers to reproduce "non-thermal biological effects" induced by pure MW carrier signals without modulation or pulsations as reported by Russian and German researchers were unsuccessful, and only thermal effects could be elicited by such exposures at higher power densities (Bush et al. 1981; Stensaas et al. 1981; Gandhi 1983; Furia et al. 1986). Wust et al. (2020; 2021) also speak of "non-thermal effects of RF fields" without reporting any measurements in the low frequencies (ULF/ELF/VLF) for the emissions of the device they used. Speaking of "RF" effects without having explored the possible coexistence of low frequencies (which unfortunately is the common case in many publications) is very misleading.

As reported earlier in this chapter, in most of the studies which compared a pulsed and/or modulated complex RF EMF with the same EMF without pulsation/modulation, it was found that it was the low frequency (ULF/ELF/VLF) pulsation/modulation and not the carrier alone that produced the non-thermal biological effects. As correctly summarized by Goldsworthy (2006), "Radio waves can also give biological effects, but only if they are pulsed or amplitude modulated at biologically active low frequencies". These facts are fully explained by the ion forced oscillation mechanism (Panagopoulos et al. 2000; 2002; 2015a; 2020; 2021), and there is no corresponding mechanism to explain non-thermal effects by high frequencies (RF/MW) alone (see Chapter 11).

Polarized and coherent ELF EMFs induce parallel and coherent forced oscillations on any charged/polar particle with energy well below the thermal level. The oscillating ions exert forces on the sensors of electrosensitive ion channels (VGICs) in cell membranes causing their irregular opening or closing with consequent disruption of the intracellular ionic concentrations and the electrochemical balance in all types of cells. This biophysical mechanism, known as "ion forced-oscillation mechanism" (described in Chapter 11 of this book), provides the basis for the explanation of the non-thermal effects of all man-made EMFs (Panagopoulos et al. 2000; 2002; 2015a; 2020; 2021). Today, the unique ability of ELF polarized EMFs to irregularly gate VGICs is widely recognized, verifying the aforementioned mechanism (Liburdy 1992; Walleczeck 1992; Pall 2013; Ceccetto et al. 2020; Zheng et al. 2021; Bertagna et al. 2021). Because of these unique properties of the man-made EMFs, EMF exposure by a mobile phone with average intensity ~ 10 μW/cm^2 on a human body may initiate adverse non-thermal biological effects, while ~ 10 mW/cm^2 (1000 times stronger) solar EMR with significantly longer exposure during the day does not (Panagopoulos 2017; Panagopoulos et al. 2015a).

While the vast majority of EMF-induced recorded bioeffects are non-thermal, heating increases with increasing RF frequency, as shown by Eq. 1.31, and may become significant with the higher frequencies employed in 5G MT technology. As, at the same time, penetration of the EMR decreases with increasing frequency (Eq. 1.2), it will likely become necessary to increase the intensity of the 5G signals in addition to the installation of huge number of additional base stations, antennas, and satellites. The existence of antenna arrays in 5G technology provides the ability of stronger and focused radiation/field beams (Eqs. 1.23–1.24). It is noteworthy that just before the massive deployment of 5G, the ICNIRP (2020) increased the limit for 6 min average exposure at 2–6 GHz from 1 to 4 mW/cm^2 (ICNIRP 1998; 2020; Panagopoulos 2020). While the older limit (1 mW/cm^2) provided limited protection against heating, the new one does not. A combination of non-thermal and thermal biological effects can be far more dangerous than non-thermal effects alone.

We discussed how WC emissions should be better described according to incident EMF than according to SAR. The argument that we need to know the power absorbed by the tissue in order to predict the biological effect has been disproven by the plethora of published peer-reviewed experimental studies, which correspond specific field/radiation intensities, frequencies, exposure durations, etc., to specific biological effects. For example, we know that WC EMF exposure with intensities ≥1 μW/cm^2 may initiate biological effects within minutes, and the effects increase with increasing intensity and exposure duration (Panagopoulos et al. 2004; 2007a; 2007b; 2010; Panagopoulos and Margaritis 2010a). We do not need to calculate the SAR by complicated methods to know this. We can predict the effect by knowing the incident radiation intensity, frequency, exposure duration, etc. We showed that a) when SAR is estimated from tissue conductivity and internal electric field, important microscopic variations in tissue conductivity are overlooked, and b) when SAR is estimated from tissue specific heat and increased temperature is significantly more accurate, but most environmental EMF exposures do not cause measurable tissue heating. Moreover, this method cannot be used in experiments with live animals, as needles/thermal probes need to be inserted, but only in experiments with cell cultures. Thus, SAR is rendered useless for the majority of EMF exposures which are non-thermal and for those involving live animals. Although, at higher MW frequencies of newer technologies (≥2 GHz) and high intensities (≥0.1 mW/cm^2) (such as 3G, 4G), there may be temperature increases at 0.1–0.3°C level (which will likely become more significant with the 5G) the biological effect of man-made EMFs is determined by field parameters not directly (or at all) included in SAR such as polarization, frequency, pulsing, modulation, variability, exposure duration, etc. Moreover, the biological effect depends on microscopic power absorption by specific biomolecules (e.g., DNA), which is not easy to estimate. Thus, SAR is of very limited value to describe bioactivity of EMF exposures. Instead, the incident radiation/field intensity at the included frequency bands should be reported along with the other field parameters, the exposure duration, variability (SD) of the measured intensity values, etc. SAR may be used complementarily in experiments with cell cultures exposed to high frequency/power MWs causing measurable heating (Panagopoulos et al. 2013b). Marino et al. (2016) have expressed similar views: "To provide an objective basis for follow-up studies, the power density of the incident radiation, which was the independent variable in the study, was characterized by direct measurement rather than by employing model-dependent dosimetry parameters, such as the specific absorption rate".

Similarly, Baker et al. (2004), even though they explored thermal effects in magnetic resonance (MR) imaging, concluded: "using *SAR* to guide MR safety recommendations for neuro-stimulation systems or other similar implants across different MR systems is unreliable and, therefore, potentially dangerous. Better, more universal, measures are required in order to ensure patient safety".

We analyzed the important issue of whether man-made EMFs/EMR consist of photons or continuous "classical" waves and the mathematical "quantization" of the EMF/EMR by the founders of QED/QEM. We showed that the mathematical "quantization" was based on the simplistic assumption that any EMF is periodic in time, allowing them to transform it into a Fourier series of discrete terms. The discrete terms were then interpreted as the "photons" of the EMF/EMR. But any random EMF is not periodic in time and, thus, cannot be transformed by application of the Fourier series. This simplistic approach started by Schroedinger, who used a harmonic wave-function to describe a free particle (Eq. 1.45). By application of the Fourier integral (Spiegel 1974), a randomly varying EMF could be theoretically transformed into a continuous of an infinite number of (non-discrete) harmonic oscillators. But this is not a "quantization". Thus, the argument that man-made (including WC) EMFs cannot induce any biological/health effects due to their small "photon energy" collapses simply because there are no such "photons", and this is in agreement with the thousands of experimental and epidemiological studies showing a vast number of adverse effects on a variety of organisms/tissues/cells.

Finally, we summarized the important differences between natural and man-made EMFs/EMR which imply that these two categories of EMFs should not be evaluated by the same criteria for their bioactivity. General concepts for the interaction of both natural and man-made EMFs/EMR with inanimate matter and biological tissue were discussed as well. We hope the presented chapter is useful in clarifying important aspects of the physical properties of man-made EMFs and, in particular, WC EMFs, which, in turn, determine their increased adverse biological activity and explain the plethora of experimental and epidemiological findings. We hope the present chapter forms a basis for the systematic study of WC EMFs and the health risks associated with exposures to these EMFs.

"This work is valuable to the society. Among many other details, it correctly identifies that 'low photon energy' must not be used to justify that microwaves are benign to living organisms. That is an irresponsible scientific thinking".
(Dr. Chandrasekhar Roychoudhuri, Photonics Laboratory, Physics Department, University of Connecticut, US)

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