Jurnal
Teknologi

Full Paper

NON-IONIZING ELECTROMAGNETIC RADIATION EFFECT ON NERVE FIBER ACTION POTENTIAL OF HUMAN BODY – A REVIEW

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Article history
Received
19 June 2015
Received in revised form
26 June 2015
Accepted
10 July 2015

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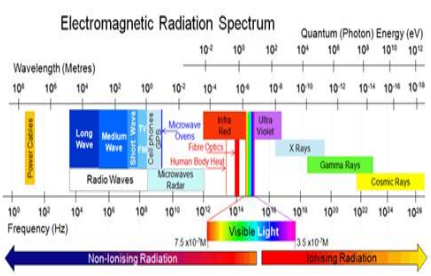
Graphical abstract



Abstract

The use of electromagnetic radiations (EM) has been increased manifold in recent times mainly due to technological advances. Electromagnetic energy was absorbed by some proportion in the human body which results to an undesirable side-effect. There is a concern on the effect of the electromagnetic radiation on biological systems in general and particularly on human nervous systems. This paper presents a review on non-ionizing electromagnetic radiation effect that has been conducted by various researchers. Through this review, we hope to provide better understanding and awareness on what is essentially happening to action potentials on electrical nerve fiber of human body if there is a presence of interference from non-ionizing electromagnetic radiation.

Keywords: Electromagnetic radiation (EMR), human body, nervous system, non-ionizing radiation

Abstrak

Penggunaan sinaran elektromagnet (EM) sedang meningkat sejak kebelakangan ini disebabkan oleh kemajuan teknologi. Tenaga elektromagnet yang diserap oleh beberapa bahagian dalam tubuh manusia mengakibatkan kesan sampingan yang tidak diingini. Terdapat kebimbangan mengenai kesan radiasi elektromagnetik pada sistem biologi secara umum dan khususnya kepada sistem saraf manusia. Kertas kerja ini membentangkan ulasan mengenai kesan radiasi elektromagnet tak mengion yang telah dijalankan oleh pelbagai penyelidik. Melalui kajian ini, kami berharap dapat memberi kefahaman dan kesedaran yang lebih baik pada dasarnya apa yang berlaku kepada potensi tindakan pada gentian saraf elektrik badan manusia jika terdapat kehadiran gangguan dari sinaran elektromagnet tak mengion.

Kata kunci: Sinaran elektromagnet (EMR), tubuh badan manusia, sistem saraf; radiasi tidak mengion

1.0 INTRODUCTION

Nowadays, every available frequency in the electromagnetic spectrum is being utilized due to the expanding technology and the need for a faster communication [1]. The most common wireless technology consists of AM and FM radio, mobile phones, radar, microwave systems and television broadcast station. The electromagnetic spectrum contains an array of electromagnetic waves such as Extremely Low Frequency (ELF) and Very Low Frequency (VLF), through Radio Frequency (RF) and Microwaves, to Infrared (IR) light, Visible light,Ultraviolet (UV) light, X-rays and Gamma rays [2].

Figure 1 is a graphical representation of the spectrum of electromagnetic energy or radiation in ascending frequency (decreasing wavelength). The general nature of the effects is noted for different ranges.

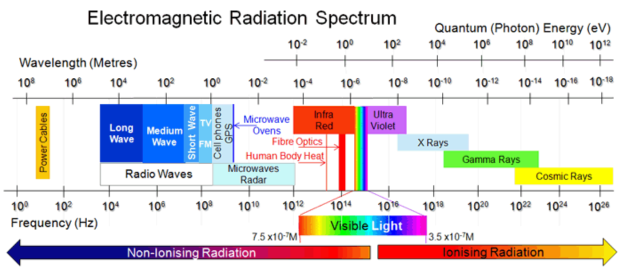


Figure 1 Graphical representation of the spectrum of electromagnetic energy [30].

The increment of man-made electromagnetic fields has an uncontrollably effects on pollution and biological values that the steps is reacting at faster rate. Electromagnetic is a type of energy that is gained from the sun. It is being transmitted in the form of wave that is the result from magnetic and electric fields [1]. The lower part of the frequency spectrum with energy levels that is below the required level to affect the atomic level are known as non-ionizing radiation. This type of electromagnetic radiation does not have enough energy to ionize atoms or molecules in other to remove an electron from molecule or atom [2].

Non-ionizing radiation encompass the long wavelength (> 100 nm), low photon energy (<12.4 eV) portion of the electromagnetic spectrum, from 1 Hz to 3 x 10^{15} Hz. The non-ionizing radiation has the ability to penetrate into the human body, the sites of absorption, and the subsequent health effects [3]. When a human body enters into a radiation field, the field will change due to the electrical properties of the body. This change is due to the different of human body properties from the original transmitting medium. The body surface mirrors some of the incident energy, while some will penetrate through the surface tissue. It is usually interact with tissue through the generation of heat. The hazard is depending on the ability of the incident energy to penetrate the human body and the absorption characteristics of different tissues.

The human body can be visualized as three layers with an equivalent thickness of 0.35 cm for the skin, 1.14 cm for the fat, and a semi- infinite layer for the muscles. As the frequency of the incident signal varies, so does the percentage of energy absorbed, as does the distribution within the different tissues. Microwaves penetrate to a depth which is equal to approximately one-tenth of the wavelength. Therefore, millimeter waves are absorbed in the skin, while decimeter waves penetrate to a depth of 10-15 centimeters. Deepest penetration occurs at 0.9 GHz, whereas minimum penetration occurs above 9 GHz [4].

Besides that, Kwan-Hoong Ng mentioned that even though the energy is insufficient to ionize atoms, single photons of ultraviolet radiation can damage tissue through interruption of bonds within DNA molecules and give a long-term risk of cancer [3]. High power densities of non-ionizing radiation can led to potential health hazards such as cancer, tumors, headaches, fatigue, Alzheimer's and Parkinson's disease. However, most researchers are unsure of how long the effects resulting from the exposure of non-ionizing radiation [2].

Mukhopadhyay reported that Committee (INIRC) of the International Radiation Protection Association (IRPA), with the cooperation of Environmental Health Division of World Health Organization has taken on the responsibility for the development of health criteria documents on non-ionizing radiation. A maximum of 2 W/kg for 10g tissue of basic restriction defined in International Commission on Non-Ionizing Radiation Protection (ICNIRP) was used to safeguard the public from electromagnetic fields. SAR can be referred as the rate of energy that is absorbed by the body when it is expose to a radio frequency (RF) electromagnetic field. Authors in [18] stated that the maximum permitted radiated power in the MICS band is 25µW.

Power absorption is described as energy photon, where in this case an electromagnetic energy that is taken up by matter refers generally to the electrons of an atom and converted to internal energy of the absorber such as thermal energy. In [18] it measures the power absorption in terms of specific absorption rate (SAR) for muscle tissue that was surrounding the implant device.

Therefore, the studies on the effect of non-ionizing electromagnetic radiation on human body were renowned to help in explaining some of unsolved biological issues like morphology, immunology, and mitosis [5].

1.1 Influence On Nervous System

Neurological effects are caused by changes in the nervous system. Elements that act directly or indirectly on the nervous system affecting morphological, chemical, or electrical changes in the nervous system can lead to neurological effects. The final appearance of these effects can be seen in psychological changes, such as memory, learning ability and perception. The nervous system is an electrical organ. Thus, the electromagnetic fields exposure could lead to changes on neurological. The highly malleable nervous system could easily recompense for external instabilities. On the other hand, the implication of neural perturbation is also situation-dependent. An electromagnetic frequency-induced change in brain electrical activity, for instance, could lead to different consequences depending on whether a person is watching TV or driving a car [6].

Moreover, the central nervous system is predisposed by certain wave components contained in the electromagnetic waves produced by a short-wave transmitter as well as in the electrical field surrounding the human body. The electromagnetic waves in the Very High Frequency range and high-frequency currents in the same range stimulate the motor nerves, the effect of which can be recognized in the reduction of the threshold of the galvanic stimulus and in the constrictor of the areas supplied by this nerves [7].

McRee *et. al* stimulated the sciatic nerve by 0.05 m/s, 2.0 V, pulses carried from pulse generator. The stimuli consist of short trains of nine pulses at 500 Hz, repeated at 5-sec intervals. McRee *et. al* observed that the first response to such a series of stimuli characterizes a pure monosynaptic reflex, the second and third responses show simplified synaptic transmission, and the last in the train are also influenced by fatigue of synaptic transmission [8].

1.2 Thermal and Non-Thermal Effects

Thermal and Non-Thermal Effects are the two mechanisms of non-ionizing electromagnetic frequency interaction with biological systems. These two effects are reliant on their attribution to deposition of heat or without heat component.

1.2.1 Thermal Effects

Thermal effects are directly happen from tissue heating due to absorption of electromagnetic frequency in dissipative medium. The motion of water dipoles and dissolved ions causes absorption of energy at microwaves frequencies [9]. The nuclei of water process around the direction of the applied field just like a gyroscope that processes around the earth's directional field.[4]

The thermal response of the body depends on SAR, body cover, thermoregulatory system, and physiological condition of environment. Therefore, the main risk of thermal damage will be the areas of low vascularity, and the most risk organ is the lens of the eye [9]. The transparent lens appears to be easily damaged by intense radiation energy, whether ionizing, infrared or microwave [4]. Other effects are relaxation of muscle spasms and increases in pain threshold of nerves [10].

1.2.2 Non-Thermal Effects

On the other hand, non-thermal effects are not intermediated by the heat which mean the effects is not associated with the increase temperature [9][10]. The effects are due to the direct interaction of the microwaves field on molecules or tissue components. Non-thermal effects are biochemical and eletrophysical effects in tissues and can result to changes in the nervous, immune and cardiovascular systems [9]. Other non-thermal effects are saturation of dielectric that takes place in proteins solution and biological molecules affect from microwave fields.

Johnson and Guy stated that the central nervous system is the most sensitive of all body systems to microwaves at intensities below thermal thresholds. There is also the reaction of the nervous system to microwave energy on brain cells and skin receptors (10). Sosnicky also stated that certain people receive a hearing response in the form of a buzzing sound when exposed to frequencies between 0.2 and 3.0 GHz in a pulse-modulated mode [4].

1.3 Implantable Device

Nowadays, implantable devices for medical technology making medication analysis easier because of its ability to penetrate through human bodies and provide data that indicate one health condition. MICS were used currently for its feature of ultra-low power, unlicensed, mobile radio service for transmitting data of diagnostic from the implant (transmitter) to external monitor device (receiver) [19].

Though the current technology of implant devices was stated to have a standard frequency of 402-405 MHz decided by the Federal Communication Commission (FCC) [20][21][22]. This frequency range is said to have a suitable propagation characteristics through human tissues. So far it comes with several disadvantages in which the demand of power hungry components for example voltage-controlled oscillator (VCO), phase-locked loop (PLL) and analog-to-digital converter (ADC) making it an ineffective factor to implant devices. Disparate UWB that having feature of simple structure, high data rate, low-power consumption and low cost give valuable aspect to the device [23][24][25][26-27], it gives perfect compatibility with the specification of an implant devices.

However, UWB were generally used for on-body or outer-body medical applications. Occasionally it is used for an in-body implantable medication device. This condition is due to the different frequency-dependent material properties of the human tissues that must be considered in the calculations [28][29].

1.4 Recent Research

A model is presented by Bradley J. Roth and Peter J. in order to explain the physics of nerve stimulation by electromagnetic induction. Maxwell's equation is used by the author to predict the induced electric field distribution that is produced when a capacitor is discharged through a stimulating coil for which the nonlinear Hodgkin-Huxley cable model. This model describes the response of the nerve fiber to this induced electric field. It is proven that the nerve fiber is stimulated by the gradient of the component of the induced electric field that is parallel to the fiber, which hyperpolarizes or depolarizes the membrane and may stimulate an action potential.

The authors stated that, if the stimulus strength is below threshold, for an example, Vo = 30 V, the fiber behaves like a passive cable and the induced voltage is dissipated. If the stimulus strength is slightly larger (Vo = 32.5 V), an action potential is evoked. They observed the resulting wave travelling in the positive x direction through the hyperpolarized region that propagates slower than the wave travelling in the negative x direction over the depolarized region [11].

Other than that, the investigation for nerve pulse propagation velocity have been carried out by H. Hinrikus, J. Lass, V. Tuulik with and without applied microwave field and different orientations of its polarization to the nerve axon. The authors also applied polarized parallel to the nerve fiber and the measured field power density at the skin was 0.87 mW/cm^2. The result of 20 measurements shows that low-level microwave radiation caused statistically significant increase in nerve pulse propagation velocity in human motor nerve fiber. They observed that microwave radiation can affect the permeability of nerve axon membrane as well as the changes in fiber membrane permeability and conductance disturb propagation velocity of the nerve pulse.

The authors said that in their case (muscle-nerve tissue, 450 MHz frequency), the normalized SAR (Wlkg) to EMF power density (rnW/cm^2) ratio factor was 0.06 while the calculated SAR value was 0.052 W/kg [12].

In other case, Ronold reviewed the function of cell membrane with reference to the transmission of frequency modulated signal and described the need for succeeding regeneration by means of action potentials. The author shows that incident 60-Hz electric fields near high-voltage transmission lines do not induce large enough currents and fields in a nerve axon of the leg to interrupt a propagating signal. He also analyzed the surface atmospheres due to exposure to electric fields in the 5–15-kV/m range and concludes that exposure to the electromagnetic field of a 60-Hz high-voltage transmission line or a 10–30-kHz high-power transmitting antenna should have no observable effect on the normal functioning of nerves.

The author describes the interaction of induced currents with a signal in the form of a concentration of ions travelling along a nerve axon in a physically accurate manner and an induced current in a nerve can suppress the regeneration and the continued propagation of a signal. The author also shown that, exposure of the human body to the 60-Hz electric field of a high-voltage transmission line of the order of 2000 V/m involves no interference with the normal function of a nerve [13].

Moreover, Shneider and Pekker observed a non-thermal mechanism of weak microwave field impact on a nerve fiber. The authors shows that in the range of about 30 - 300 GHz, there are strongly obvious resonance related with the excitation of ultrasonic vibrations in the membrane as a result of interaction with electromagnetic radiation. They stated that these vibrations create acoustic pressure which causes the redistribution of the protein transmembrane channels. Thus, the threshold of the action potential excitation in the axons of the neural network will change. It is shown that the non-thermal microwave field can affect the ultrasonic mechanical vibrations in the nerve fibers. Collaborations with the ultrasound vibrations could change the density of transmembrane protein sodium channels. As a result, it could also change the resting potential in the nerve fibers and, hence, it may induce or, conversely, overwhelm the excitation of the action potentials [14].

Nagarajan and Durand evaluated four such models of an axon located in: 1) an isotropic nerve bundle with no perineurium, 2) an anisotropic nerve bundle without a perineurium, 3) an isotropic nerve bundle surrounded by a perineurium, and 4) an anisotropic nerve bundle surrounded by a perineurium. The transmembrane polarization that was compute along an axon for the above four models is compared to that for an axon located in an infinite homogenous medium. The existence of a perinerium around the nerve bundle and anisotropy in the bundle affects the shape of the transmembrane response. The authors said that, models of isolated axons are good predictors of excitation sites for axons in a sheathless nerve bundle. However, membrane depolarization of an axon in a sheathed nerve bundle with a perineurium is smaller compared to that of an isolated axon. Therefore, anisotropy in the nerve bundle conductivity as well as the presence of a perineurium can substantially disturb the amplitude of transmembrane polarization and the location of excitation along a nerve [15].

Masaki *et. al* investigate the effects of strong static magnetic fields on the action potentials of the rat sciatic nerve. Masaki *et. al* said that the exposure to a static magnetic field did not affect the amplitude of the action potentials. An increase in the static magnetic field increases the amplitudes of the peaks of the C fiber. They also specified that exposure to strong static magnetic fields improves the excitation of nerve fibers, and this effect be influenced by the type of fibers involved [16].

Cretu, Darabant, and Ciupa present a model that combines circuit analysis with Maxwell's equations of electromagnetic theory and non-linear cable theory. This theory explains the action of the induced electric field upon a nerve fiber. The magnetic coil considered in their simulation has 30 turns, a radius of 25 (mm) and the wire's radius is 1 (mm). The computed inductance of this coil is 0.165 (mH). The coil is part of a magnetic stimulator that also comprises a capacitance, C=200 (μF). The electric field gradient represents the activation function and is calculated along the mcylinder (the arm) – Oz axis, on a line with y=0 (mm) and x= 25–6.25 = 18.75 (mm), that is on a depth of 6.25 (mm) in the tissue, below the edge of the coil.

The model is used to determine the response of the nerve membrane and the action potential to the applied electric field, for different values of the initial voltage on the capacitor of the stimulation circuit. For overdamped transient state of the circuit, the variability of the parameters leads to a change of the excitation threshold up to 21.6% compared to the standard model.

For the underdamped state, the threshold for variable parameters is double compared to the initial one (17).

2.0 CONCLUSION

The non-ionizing electromagnetic radiation effect was reviewed as well as it influence to nervous system. The exposure to electromagnetic fields could lead to changes on neurological in nervous system. Thermal and non-thermal effects due to EMF absorption in humans were reviewed. The organ that is most at risk of thermal damage appears to be the lens of the eye while non-thermal effects are reported to occur at levels well below, those in which the thermal effects become to be observed.

This research review is expected to provide awareness on what essentially happens to electrical nerve fiber of human body if there is interference from non-ionizing electromagnetic radiation. This reviewed also will be useful to lead the way in understanding the potential human health hazards of electromagnetic radiation.

Acknowledgement

We are grateful to Centre for Telecommunication Research and Innovation (CeTRI) and Universiti Teknikal Malaysia Melaka (UTeM) for supporting us to complete this study using the grant PJP/2013/FKEKK (39C) /S01251 and supplying the electronic components and equipment's from the laboratory.

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