Journal of Genetic and Environmental Resources Conservation, 2021, 9(1):183-189.
www.gercj.com Print ISSN: 2306-8663, Online ISSN: 2306 – 8280

The biological effects of radio waves on human body tissues

Zina A. Al Shadidi* and Mirfat Al Shaddadi
[1]Physics department, Saber Faculty of education, University of Aden, Yemen and [2]Physics department, Faculty of Education, University of Abian, Yemen
*Corresponding author: zabaqer@yahoo.com
Received: October 18th 2020; Accepted: November 14th 2020

Abstract

The radio waves are part of the non-ionic electromagnetic radiation that occupy the range (100KHz-300GHz). RF frequency radiation is existed in a lot of devices such as the mobile phone, radio stations, and medical devices. There are many symptoms and side effects that result from the exposure to such radiation. The Heart and brain tissues, were the most affected tissues by the RF waves. There is no evidence regarding these side effects on humans, although there are numerous frequent scientific researches on this subject. This study deals with a review of the most important scientific aspects that must be studied in this field, namely the thermal and non-thermal effects on human tissues. The calculation leads to conclude that a special RF band have low frequencies matches with the tissues molecules frequency, to make a resonance causes damage to human body cells.

Keywords: Radio waves, Human tissues, Thermal, Non-thermal effects.

Introduction

The exposure of RF fields at certain circumstances may lead to the biological responsive such as heating of tissue, changes at the chemical processes into the body, or the influence on electric currents in the tissues and nerve stimulation (NS). Here, we can put two outlines of biological responses : a) Heating of tissue involves and all effects that resulting from that, b) The nerve stimulation (NS) involves and all effects that resulting from that (Betski, 1999; Soichi, 2006; Gregory, 2013).The stimulation of instantaneous electric currents into the tissue by RF fields above 100KHz may lead to NS, but these effects are not clear (Soichi, 2006). At the range of frequencies between 100KHz-10MHz we have the all probabilities that mentioned above, but the preferences to heating tissue by absorption of RF energy (W. Soichi,2006 Betski, 1999). At frequencies above 6GHz the expected damages are related by deposition of energy in the uppermost layers of tissues such as skin, cornea (Betski, 1999). Some studies determines the basic restrictions that controlled occurrence the biological responsive, in general the ratio of energy absorbed and the strength of internal electric fields ,voltage gradients and currents are the most important factors to occurrence the responsive (Betski, 1999; Soichi, 2006; Guillaume, 2016; Tanghid, 2017). The reaction of microwave power is highly selective where at certain frequencies the reaction of cells becomes extremely strong (Smolyanskaya, 1973, Adey, 1983) .

The interaction of RF radiation with the tissues of the human body: The human body has a weak electromagnetic field. When it exposed to the external electromagnetic field, it interacts with the external field and this interaction may affect human health. A plane electromagnetic wave traveling in a positive one dimensional direction can be described by (Adey, 1983)

$E(z) = Ee^{-\gamma z}$...............(1)

E is the complex amplitude of the signal at z = 0, z the propagation distance and γ the complex propagation constant (Betski, 1999). In general the complex propagation constant of a wave can be specified as:

$\gamma = \omega\sqrt{\mu\varepsilon} \ldots\ldots\ldots\ldots\ldots(2)$

with $\mu = \mu_r \mu_0$ the permeability of the material, which is equal to μ_0 because $\mu_r = 1$ for biological materials, and the permittivity $\varepsilon = \varepsilon_0 \varepsilon_r$.

The biological tissues of the human body are not homogeneous where it consists of many different components, the most important component is a water (dipole molecule)addition similar cells, dissolved organic molecules, and insoluble matter (Ross, 1983; Hinchliffe, 2015; Tanghid, 2017).

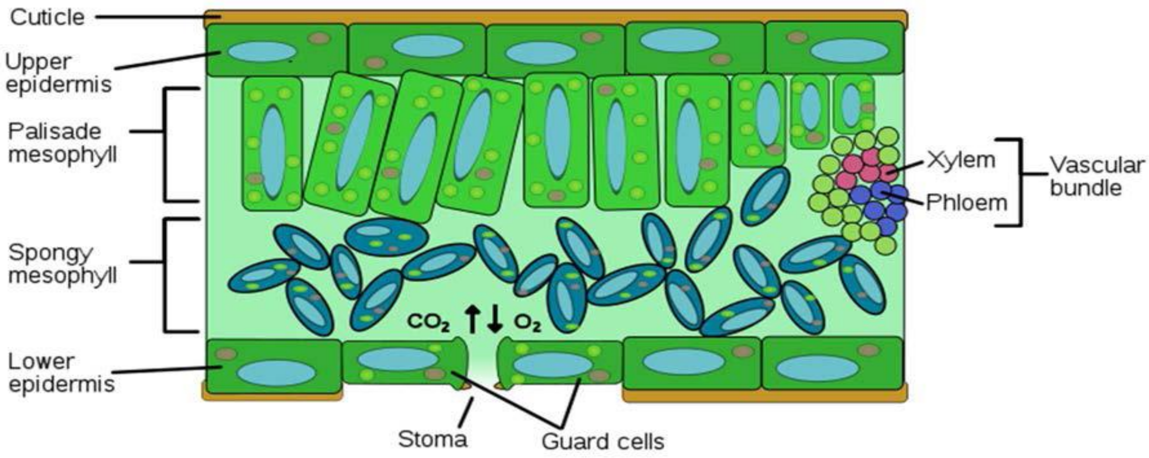

Figure 1: Cross section of leaf tissue

where each component interacts with the external field by different way, the reason is the difference in the relative permittivity (the dielectric constant) of each of them, So the tissue display different polarization mechanisms that shown in following:

1-Polarization by dipole alignment: Occurs at a polar material that has a dipole molecules such as the tissue's water where interaction with RF frequencies that over HF frequency until the microwave region.

This interaction is representing by the alignment the dipole towards the external field, this process is continuous to the external field frequency becomes equal to the resonance frequency, in this case, the dipole is not able to keep track of change at the external field.

for alignment the dipole must overcome some molecular and atomic forces, so it is there absorption for some the electromagnetic energy that travels through the material, and the difference in the phases between the applier external field and the polarization.

This process may be associated by rises the temperature of tissue that is known by the dielectric loss (Gregory, 2013; Tanged, 2017), here the relative permittivity is complex as shown in equation (3).

$$\varepsilon^*(\omega) = \grave{\varepsilon}_r(\omega) - i\grave{\grave{\varepsilon}}_r(\omega) \dots\dots (3)$$

$\grave{\varepsilon}_r$ *is the real part of the relative permittivity*

$\grave{\grave{\varepsilon}}_r$ *is the imaginary part of the relativepermittivity.*

by putting equation (3) into equation (2) γ can expressed as

$$\gamma = \omega\sqrt{\mu\varepsilon} = \omega\sqrt{\mu(\varepsilon' - i\varepsilon'')} \dots\dots\dots(4)$$

So :

$$\gamma = \omega\sqrt{\mu\varepsilon'}\sqrt{1 - i\frac{\varepsilon''}{\varepsilon'}} \dots\dots\dots(5)$$

The loss tangent is defined as the ratio of the imaginary permittivity and the real permittivity:

$$\tan\delta = \frac{\varepsilon''}{\varepsilon'} \dots\dots\dots\dots(6)$$

The complex propagation constant can also be expressed as:

$$\gamma = \alpha + i\beta \dots\dots(7)$$

where the real part describes the attenuation constant α of the wave and the imaginary part the phase constant β. To calculate (α,β) we take the real part and imaginary part of the complex propagation constant $\{i\gamma\}$: (Frenkel,, 2002; Hinchliffe, 2015).

$$\alpha = Re\{i\gamma\} = \omega\sqrt{\left(\frac{\mu_0\varepsilon'}{2}\right)\left[\left(\sqrt{1+\left(\frac{\varepsilon''}{\varepsilon'}\right)^2}\right)-1\right]^{\frac{1}{2}}} \dots\dots(8)$$

$$\beta = Im\{i\gamma\} = \omega\sqrt{\left(\frac{\mu_0\varepsilon'}{2}\right)\left[\left(\sqrt{1+\left(\frac{\varepsilon''}{\varepsilon'}\right)^2}\right)+1\right]^{\frac{1}{2}}} \dots\dots(9)$$

The phase velocity and the wavelength of an electromagnetic signal is defined as:

$$v_p = \frac{\omega}{\beta} \dots\dots\dots(10)$$

$$\lambda = \frac{2\pi}{\beta} \dots\dots\dots\dots\dots(11)$$

The polarization by a dipole alignment decrease by increasing material's temperature.

2-Ionic Polarization: due to separation of positive and negative ions at a molecule, this polarization is continuous to IR region (Tanghid, 2017).

3-Electric Polarization: due to the movement of negative charge (electrons) away from the positive charge (nucleus) in the atom for distance equal to dipole's length. This polarization is continuous to the UV region, it occurs at the material of nonpolar molecules (Tanghid, 2017).

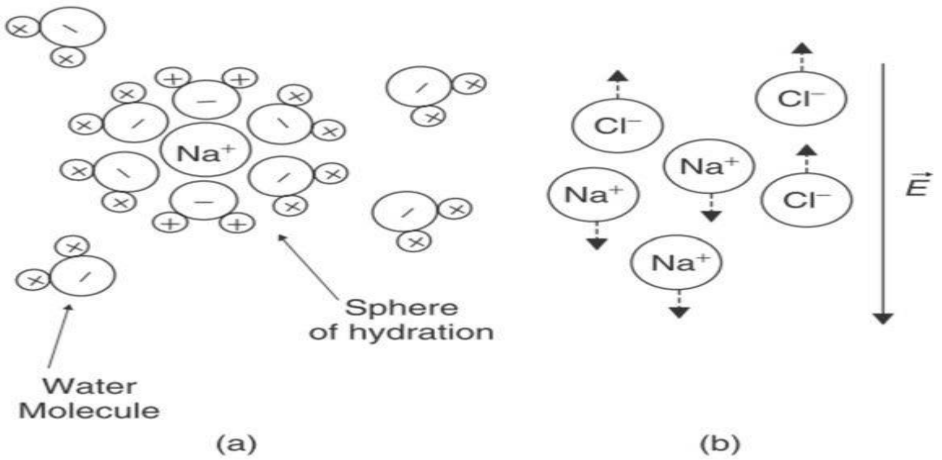

Figure 2: (a) positive Sodium ion associated with and surround by the polar water molecule (b) because of applied field, ions are displaced, inducing ionic polarization

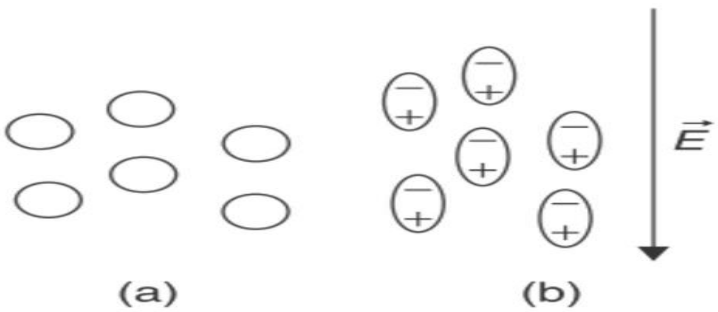

Figure 3: (a) Atoms when no external electric field applied (b) Electric dipoles induced as the externally applied electric field distorts the electron cloud

Debye equation one of the mathematical formula to describe the complex relative permittivity [1,2], that is shown in equation (11)

$$\varepsilon_r^*(\omega) = \varepsilon_r(\infty) + \frac{\varepsilon_r(0) - \varepsilon_r(\infty)}{(1 + i\omega\tau)} \ldots (12)$$

$\varepsilon_r(\infty)$ *is the permittivity(dielectric constant)in the highest frequencies,* $\varepsilon_r(0)$ *is the permittivity in the low frequencies the static permittivity is realized in full.*

By comparing equation (11) with equation(3),we can separate the real part and imaginary part of the complex relative permittivity.

By multiplying the numerator and the denominator in equation (11) by $(1 - i\omega\tau)$:

$$\varepsilon_r^*(\omega) = \varepsilon_r(\infty) + \frac{\varepsilon_r(0)-\varepsilon_r(\infty)(1-i\omega\tau)}{(1+i\omega\tau)(1-i\omega\tau)} \ldots\ldots\ldots(13)$$

So, the real part of the complex relative permittivity is

$$\varepsilon_r^{`}(\omega) = \varepsilon_r(\infty) + \frac{\varepsilon_r(0) - \varepsilon_r(\infty)}{(1 + \omega^2\tau^2)} \ldots\ldots (14)$$

The imaginary part is:

$$-i\varepsilon_r^{``}(\omega) = \frac{-i(\omega\tau\varepsilon_r(0)-\tau\omega\varepsilon_r(\infty))}{(1+\omega^2\tau^2)} \ldots\ldots\ldots(15)$$

$$\varepsilon_r^{``}(\omega) = \frac{\omega\tau\varepsilon_r(0) - \tau\omega\varepsilon_r(\infty)}{(1 + \omega^2\tau^2)} \ldots\ldots\ldots\ldots (16)$$

For the relaxation mechanisms that are not first order, this means that higher order equations must be used to model these materials [1,2],

$$\varepsilon_r^*(\omega) = \varepsilon_\infty + \frac{\Delta\varepsilon_1}{1 + i\omega\tau_1} + \frac{\Delta\varepsilon_2}{1 + i\omega\tau_2} + \cdots + \frac{\Delta\sigma_i}{1 + i\omega\varepsilon_0} \ldots (17)$$

$\Delta\varepsilon = \varepsilon_\infty - \varepsilon_{0\ and\ \sigma_i}$ is the static ionic conductivity of the tissue.

Cole-Cole relaxation model can be extended to allow for multiple relaxations in the same way as the Debye equation.

$$\varepsilon^* = \varepsilon_\infty + \frac{\varepsilon_\infty - \varepsilon_0}{1+(i\omega\tau)^{1-\alpha}} \ldots\ldots\ldots\ldots(18)$$

This equation allows a better fit to the real relaxation curves of many tissues (Gregory, 2017)

As mentioned above, we resulting that the relative permittivity determined the tissue's components responsive to the external field, where it depends on the frequency. The relative permittivity decrease with increase the frequency of external field, which is classified into three phases as follows:

α - dispersion: Occurs at the low frequencies (under 100KHz) that is featuring by penetration depth larger than the highest frequency. Here the relative permittivity is highest and realized in full, meaning the imaginary part of the relative permittivity is zero.

β -dispersion: Occurs at the medium frequencies between 100KHz-10MHz, these frequencies have penetration depth lower than the frequencies in α dispersion, the penetration depth for it arrives to the cellular membranes.

γ - dispersion: Occurs at the highest frequencies above 10MHz, the penetration depth for these frequencies lower than the penetration depth of the frequencies at the α and β dispersion.

This dispersion due to alignment the polar molecules of tissue's water, here the Relative permittivity decreases with increasing the frequency and the water lose the dielectric properties versus increase the alternating conductivity, that leads to rising the temperature of the water and it starts by evaporation that may lead to the dryness of tissue (Tanghid,2017, Soichi ,2006, Betsk, 1999)

-The alternating conductivity associated with frequency by equation(19)

$$\sigma(\omega) = \varepsilon_0 \varepsilon_r^{''} \omega \ldots \ldots \ldots (19)$$

- skin depth can be calculated using Equation by equation(20)

$$\delta = \sqrt{\frac{2}{\omega\mu\sigma}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots(20)$$

The biological effects of RF radiation on the human body tissues: There are many types of RF radiation sources, some are near of the human body as mobile phone, and some far as radio stations and wireless stations. It plays the main role of exposure human to the radiation that emits from it, whether the long-term exposure or the short-term exposure.

The federal communications commission (FCC) determined unit for the safe exposure levels for the RF radiation that emits of mobile phone, it namely specific absorption radiation (SAR).

SAR is a dosimetric quantity, it defined as the rate of RF power absorbed per unite mass by any part of the body, FCC determined the SAR by the value (1.6watt/kg). When SAR is over this value that is meaning that a mobile phone overrun the safety boundary and it forms dangerous on the human health, that represents by rises the tissue temperature and probability occurrence a dangerous biological damages (Gregory, 2013; Guillaume, 2016; Tangid, 2017) .

RF effects on the human tissues classified to:

1-Thermal Effects: Thermal effects associated by heating tissues, this effects appears with the heights frequencies that have a lower penetration depths which arrive to region near of skin that contains the sensuous cells thus we will feel by heating when we exposures to this frequencies, the body try reparation that by sweating or increase the blood flow to keep the tissue at a normal temperature, but when rises the temperature of tissue over determinant levels then the biological effects appears and may not remove by stooping the exposure that lead to dryness and burn the tissue, may damage in the nervous cells ..etc.

These effects are unobservable until arrives the rise in the temperature of tissue to $4.5c^0$ in period $30\ \mathrm{min}$. The rise in the temperature of tissue at the short-term exposure related with SAR by a linear relationship, but at the long-tern exposure the relationship between them becomes more complicated (Ross, 1983; Hinchliffe, 1988; Betski , 1999; Belgium, 2015; Tanghid, 2017).

2-Non-thermal Effects: These effects related to induced electromagnetic effects into the body's cells due to the durable exposure to low frequencies of RF radiation under the SAR to a long period as staying near a wireless antenna or usage of the headsets constantly.

According to ANSI, this damages is not thermal effects meaning it no related by heating a tissue but it is biochemical and physiologist damages as a metabolism, the influence on the electrical signals for the heart and brain, there are several studies said that damages may be cumulative at the long-term exposure (Ross, 1983; Hinchliffe, 1988; Betski, 1999; regory, 2013; Belgium, 2015; Tanghid, 2017).

Previously, the studies were connecting between the excess dosimetric of SAR over the recommendable boundary by the US and rises the temperature of tissue for the occurrence of biological damage into the tissue. At recent years, a lot of modern studies discussed the probability of biological damages by the exposure to the low frequencies of RF under the recommendable dosimetric of SAR for a long period, but these studies have not ascertained to this damage. The searchers overbalances that the reason belongs to that non-interpolation the necessary conditions to this researches, such as, to investigate that the mobile phones frequencies may be a reason to the cancer we need to a long study because the cancerous cells may need 15 years to appear, Some mobile phone users in many studies tell about several feeling unspecific symptoms when use it as tingling sensation in the skin of the head, fatigue, sleep disturbance, headache, dizziness, lack of concentration…etc. Gregory, 2013, Frenkel, 2002, Robert 2002)

Mathematical model: DNA consists of two polynucleotide chains infected with a double helix, each chain contains a number of nucleotides. These nucleotides are made from one of four sugar bases: adenine (A), thymine (T), guanine (G), cytosine (C). The bases are linked together by covalent bonds forming the DNA, and the two chains are carried together by hydrogen bonds between the bases on the two paths. The whole series of double rules is the so-called genome that determines the genetic information.

The total potential energy inside any system consisting of a number of interconnected particles is calculated according to molecular dynamic, the potential energy of any number of bounded particles according to the following equation (Betski 1999; Guillaume 2016):

$U = U_{fene} + U_b + U_{ev}$………………..(21)

Where U_{fene}:is the finitely-extensible non-linear elastic potential (FENE) the so-called gravitational basin, which is the linear phase of the reaction. Within this kind of interaction, any changes in the two bodies energy will ends with its impacts with the disappeared of influential. The second type is exiting when the second body is outside of the effective volume, because of the increasing applied power on it, this stage is called the nonlinear phase of interaction. The impact at this stage becomes a cumulative.

In order to exam the effect of the radio waves energy on the human body molecules. The intermolecular energy will be calculated and compared with the energy of the RF waves.

If we assume that the bonds $u_i$have Gaussian distribution, our calculation will be done according to Gaussian chain model, which is equivalent to group of monomers linked one to another by harmonic springs as in the following figure (4). The potential energy in the non-linear stage is given by the following equation (IIKA 2014, 2018):

$U_{fene}[\{r_i\}] = \frac{3k_e r_0^2}{2b^2} \sum_{i=1}^{N} \ln\left(1 - \frac{u_i^2}{r_0^2}\right)$… --------(22)

In the case of the effect of radio waves on the DNA, the considered calculation was according to ri =20 , where r0 is a distance above which non-linear effects start to appear in the bonds elasticity, and k_e is the rigidity constant of the non-linear spring. Note that for $ui \ll r0$ .. In practical applications , $k_e = k_\beta T$ [14,4,6]we will generally take $r0 = 1.5b$ and $ke = 10\ kBT, \langle u_i{}^2\rangle = b^2$.

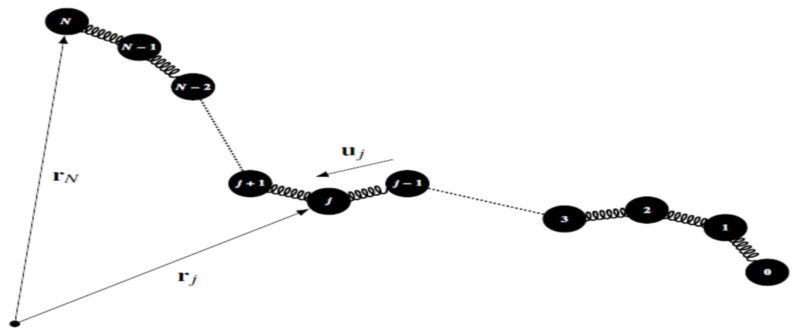

Fig (4): the Gaussian chain model describing the DNA

U_b : The Kratky-Porod chain potential

U_{ev}: the truncated Leonard- Jones potential

In molecular dynamics, we can say that the interaction between two bodies is divided into two parts according to the amount of energy exerted on the body, and the period of exposure to this energy, the first section is the interactions within

$\beta U_e[\{r_i\}] = \frac{3}{2b^2} \sum_{i=1}^{N} (r_i - r_{i-1})^2$……..(23)

The DNA chain can be represented as a polymer chain, with great curved stiffness, and this could be defined with the potential of Kratky-Porod chain as follows (Betski, 1999)

$U_b[\{r_i\}] = \beta^{-1} K \sum_{i=1}^{N-1} (1 - u_i \cdot u_{i+1})$…..(24)

Where k is the curved stiffness modulus, which is represented by the thermal heat $k_\beta T$, suppose that stiffness modulus equal to $10k_\beta T$, β represents the potential contributions in the molecular assembly. (Smolyanskaya, 1973; Ross 1983; Hinchliffe, 2015).

The DNA for human tissues differs with the tissue type, in addition to that the single tissue is considered as a heterogeneous when talking about the optical and insulating properties. Therefore β will be different for every different kind of tissues, and it will be equal to one for the aggregate tissue.

$$k = l_p, \ where \ \ l_p = 20b(for\ naked\ DNA)$$

In this aspect the Lenard-Jones potential will appear in our calculations.

$$U_{ev} = \begin{cases} V_{lj}(r) - V_{lj}(r^{th}) & if\ r < r^{th} \\ 0 & otherwise \end{cases} \ldots (25)$$

V_{lj}: *the pair potential of Lennored − Jones*

$$V_{lj}(r) = 4\varepsilon\left[\left(\frac{\sigma}{r}\right)^{12} - \left(\frac{\sigma}{r}\right)^{6}\right] \ldots (26)$$

$$U(r) = V_{lj} - V_{ljth} = V_{lj} - (-V_{lj}) = 2V_{lj} \ldots (27)$$

for r^{th}*distance*

$$U_{ev} = \frac{1}{2}\int_{r^{th}}^{\infty} dr\ 4\pi r^2\ Nu(r) \ldots \ldots \ldots \ldots (28)$$

When $r < r^{th}$, *N will be equal to the assumed particle rate within the range in which we compute, substitute for u (r) with* V_{ij} *Leonard Jones voltage, we will get*:

$$U_{ev} = -16\pi N\varepsilon\left(\frac{5\sigma^3}{18\sqrt{2}}\right) \ldots\ldots (29)$$

Within this concept the natural potential for the DNA particles keep them tight together. and the RF wave potential will not be enough to make a distortion. In fact the RF wave potential can cause deformation if the frequency of these waves matches the natural frequency for the particles making up the tissue, or its binding.

A Matlab code established to simulate resonance effect of the low frequency RF wave with the natural frequencies of the human cells. According to this simulation, a doubling in the wave amplitude occurs due to the resonance which may lead to the damage .

Our results agrees with what Ivančica 2012, Mobin Marvi and Majid Ghadiri 2002, Robert K. Adair results 2002, Lin Dong 2015.

Conclusions

1- Tissue display different polarization mechanisms shown as follows:

a-Polarization by dipole alignment:

b- Ionic Polarization

-the relative permittivity determined the tissue's components responsive to the external field, where it depends on the frequency.

-The relative permittivity decrease with increase the frequency of external field.

-Its classified into three phases(α dispersion, β dispersion, γ dispersion)

c- Electric Polarization

2- The sources of radio waves calcified to : near of the human body as mobile phone, and some far as radio stations and wireless stations.

3- specific absorption radiation (SAR). SAR is a dosimetric quantity, it defined as the rate of RF power absorbed per unite mass by any part of the body, FCC determined the SAR by the value (1.6watt/kg).

4- RF effects on the human tissues classified to: thermal effects and non-thermal effects.

References

Adey, R. W. and Lawrence, A. F. 1983. Nonlinear Electrodynamics in Biological Systems, Platinum Press, New York and London.

Alan, Hinchliffe, 1988, Molecular Modelling for Beginners, Wiley, UK.

Betski, OV, 1999, Microwave radiation passage through the barriers. The interaction of microwaves with the human body. Radio, N 10: 47-53.

Brussels, Belgium & Bilbao Spain, 2015. Non-linear dynamic in biological system, Jorge Carballido-Landeira,Bruno Escribano, Springer.

Dan, Frenkel, Michael Klein, Michele Parrinello, & Berend Smit, 2002, understanding molecular simulation from algorthims to applications, Scadimic Press, UK.

Emanuele Calabro & Salvatore Magazu, 2014, Resonant interaction between electromagnetic fields and proteins: A possible starting point for treatment of Cancer, Electromagnetic Biology and Medicine, 18, pp. 155-168.

Gregory, M. 2013. Electromagnetic Absorption by the Human Body from 1 to 15 GHz. A thesis submitted for the Ph.D. degree.

Guillaume, LE TREUT, 2016, Models of chromosome architecture and connection with the regulation of genetic expression, PhD thesis University, Paris-Saclay, Institut de Physique Théorique, and, Institute of Systems and Synthetic Biology, 29 November..

IIKA, D. 2014. Analysis of Radio Propagation Inside the Human Body for in-Body Localization Purposes, M.Sc. Thesis.

Ivančica, TROŠIĆ, Ivan PAVIČIĆ, Ana Marija MARJANOVIĆ, and Ivana BUŠLJETA, 2012; NON-THERMAL BIOMARKERS OF EXPOSURE To RADIOFREQUENCY / MICROWAVE RADIATION, Arh Hig Rada Toksikol 63 Supplement 1: 67-73.

Limits of Human Exposure to Radiofrequency Electromagnetic Energy in the Frequency Range From 3 KHz to 300 GHz. Health Canada, Safety Code 6 ,2015.

Lin Dong, Michael Grissom , and Frank T. Fisher 1, 2015, Resonant frequency of mass-loaded membranes for vibration energy harvesting applications, AIMS Energy · Volume 3, Issue 3, 344-359.

Mobin, Marvi & Majid Ghadiri, A Mathematical Model for Vibration Behavior Analysis of DNA and Using a Resonant Frequency of DNA for Genome Engineering, www.nature.com/scientificreports.

Robert, K. Adair, 2002. Vibrational Resonances in Biological Systems at Microwave Frequencies, Biophysical Journal, 82: 1147–1152.

Smolyanskaya FZ, Vilenskaya RL, 1973, Effect of Electromagnetic Radiation of a Millimetre Range on Functional Activity of Genetic Elements of Bacterial CellsUspekhi Fizicheskikh Nauk, 110(3): 458-460 (in Russian).

Soichi, W., Tomoaki N., Kanako W., Masahiro H., P. Pornanong, 2006. Research on Biological Effects of Radiofrequency Radiation and on Evaluation Methods of Compliance with Radiofrequency Radiation Protection Guidelines.

Tanghid, R. 2017. Analysis of Biological Effects of Cell Phone Radiation on Human Body Using Specific Absorption Rate (SAR) and Thermoregulatory Response. Thesis Submitted for the Degree of Master of Science.