Biological Effects and Therapeutic Applications of Electromagnetic Radiations

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Abstract

The electromagnetic fields have a great influence on the behavior of all the living systems. The human body itself is a source of naturally generated electric and magnetic fields. When external signals of comparable strength flows through the human body; the nature of changes that such signals could induce in natural electrochemical processes and voltage is a subject of interest and of considerable biomedical research. When analyzing the interaction between the electromagnetic fields and human body, two main objectives can be identified. First of all electromagnetic fields can be considered as harmful to the health. Using the results of epidemiological studies and by application of the ALARA (As Low As Reasonably Achievable) principle, the governments have imposed some limitations to the authorized radiated fields by the power systems. Secondly the electromagnetic fields can have very positive properties for medical treatment and for medical diagnosis of some health problems. As example, hyperthermia is used in oncology treatment to treat localized cancerous tumor.

Either we want to be protected from the fields, or we want to take benefit of the positive effects of these fields, all the effects thermal as well as genetic have to be well known. In both the cases the electromagnetic field distribution has to be computed in human body taking into account all the particularities of the system. The interaction between electromagnetic fields and biological tissue is one of the great challenges.

Various numerical models have been developed for the calculation of electromagnetic fields on humans considering the human body as a simple geometrical model with uniform material properties. The finite element method has been proven to be a powerful tool for calculation of electric, magnetic and thermal fields. Its capability of modeling strongly heterogeneous structures has been proved. This method is most widely used technique for engineering design and analysis, approximates the solution of various differential equations and boundary problems.

Keywords: EMF, Hyperthermia, MCT, Ablation, SAR

1. Introduction

The electromagnetic environment is an integral part of the world in which we live. Electromagnetic field or EMF is referred to as the presence of electromagnetic radiation, which consists of waves of electric and magnetic energy moving together through space at the speed of light. EMF is generated when an electric current runs through a wire or an appliance. These fields are characterized by a pair of vector fields of electric field, E (V/m) and magnetic field, H (A/m).

2. Biological Effects of Electromagnetic Radiations

Electromagnetic fields can be considered as harmful to the health. Various apparatus such as radio and television broadcast stations, computers, microwave ovens, cellular phones, surveillance systems and communications satellites and navigational aids radiate electromagnetic energy during their normal operation. The pollution from man-made electromagnetic fields has increased so rapidly and uncontrollably that the biological consequences have paced up even at a faster rate[1]. It is well known that the EM fields penetrate deep inside the living tissue: consequently the biological systems get affected. It is believed that the association of electromagnetic fields increases behavioral changes and health problems such as epilepsy, leukemia, cancer, brain tumor, Parkinson’s disease, fatigue, headache, and loss of appetite, de- creased blood pressure, itching and alteration in the gene expression etc. Many scientists and physicians suggest a link between these disorders and long- term exposure to EMF [2, 3]. The most important of all the "biological clock" of the human system has been affected adversely. Hence effects of EM fields on biological systems are a new and dynamic area for research and are a combination of biology and physics.

Table 1 below illustrates some typical artificial sources of electromagnetic fields with frequency and intensity. Natural sources like the magnetic field of the earth are not included.

Frequency Range	**Freq-uency**	**Some Examples of exposure sources**
Static	0 Hz	VDU (Video displays); MRI and other diagnostic scientific instrumentation, Industrial electrolysis
ELF	0-300Hz	Power lines, Domestic distribution lines, Domestic appliances, Electric Engines in the car, train and tramway
IF	300Hz-100KHz	VDU, Anti theft devices in shops, hand free access control system, Card readers and metal detectors, MRI
RF	100kHz-300GHz	Mobile telephony, Broad casting and TV, Microwave oven, Radar, Portable and stationary radio transceivers, personal mobile radio

Table1. Typical sources of electromagnetic fields

Using the results of epidemiological studies and by application of the ALARA (As Low As Reasonably Achievable) principle, the governments have imposed some limitations to the authorized radiated fields by the power systems. It has been proposed a set of maximum values of current density or specific absorption rate (SAR), according to the frequency. These values are called the basic restrictions, and reference levels for the fields are derived from these restrictions using measurement or computational techniques performed on very simple models. Unfortunately these reference levels are only external values. They cannot take into account the way the field develops inside the body and they do not take into account the environment of the exposed person. It is now necessary to increase the knowledge of the distribution of the fields inside the body in order to give a more acceptable limit to these radiated fields.

In1996,theWorld Health Organization (WHO) established a program (the International EMF Project) designed to review the scientific literature concerning biological effects of electromagnetic fields, identify gaps in knowledge about such effects, recommend research needs, and work towards international resolution of health concerns over the use of RF technology.[4]

Exposure standards and guidelines have been developed by various organizations and countries over the past several decades. Not all standards and guidelines through out the world have recommended the same limits for exposure. For example, some published exposure limits in Russia and some eastern European countries have been generally more restrictive than existing or proposed recommendations for exposure developed in North America and other parts of Europe [5]. This discrepancy may be due, at least in part; to the possibility that these standards were based on exposure levels where it was believed no biological effects of any type would occur.

This philosophy is in consistent with the approach taken by most other standards-setting bodies which base limits on levels where recognized hazards may occur and then incorporate appropriate safety margins to ensure adequate protection.

3. Therapeutic Applications of Electromagnetic Radiations

Several medical applications use electromagnetic fields in the RF range for example for medical diagnosis (medical scanning MRI) or for medical treatment. Therapeutic applications such as soft tissue healing appliances, hyperthermia for cancer treatment, or diathermy expose the patient well above the recommended limit values to achieve the intended biological effects. As example, hyperthermia is used in oncology treatment to treat localized cancerous tumor [6]. The elevation of temperature in the tumor is obtained by submitting locally the patient to a radiofrequency (RF) electromagnetic field. The focalization of the heat inside the tumor is obtained by using several RF sources having specific phases and amplitude. The values of optimized source currents are obtained by coupling the electromagnetic field computation inside the body with an optimization process.

These include heating of tissue (analgetic applications) or burning cells (to kill cancer cells). In these cases exposure of therapists or other medical personnel needs to be controlled to avoid that their exposure exceeds the exposure limit values foreseen by Directive 2004/40/EC for occupational exposure. Diagnostic applications, like magnetic resonance imaging (MRI), are allowed to exceed the basic restrictions of Council Recommendation 1999/519/EC as there is a benefit for the patient.

4. Use of COMSOL Multiphysics

In both cases the electromagnetic field distribution has to be computed in the human body, taking into account all the particularities of that "system": the "material" (the human body) has very unusual electromagnetic properties values: electric permittivity, electric conductivity, these properties are not well known and depend on activity of the person, this material is an active material at the cell scale, in most cases, the problem is actually a coupled problem : the thermal effect is one of the major effects and it is affected by the blood circulation, the human geometry is complex and generally environment of the human body has to be taken into account.

Determination of SAR can be made either by using sophisticated computer modeling techniques or by performing tests on a model called a "phantom". Years of research have gone into understanding and developing ways to calculate the complexities involved in determining SAR values for products that produce radio frequency emissions. The results of that research are the current and recently revised FCC RF emissions guidelines based on the ANSI/IEEE and NCRP standards. [7-10].

Application of simulation software based on various mathematical methods (FEM, FDTD, etc.) for modeling of various physical processes for research and education purposes has grown rapidly in recent years. Although re-searcher is able to solve various problems analytically or using various approximations, when the problem becomes too complex, one needs to use numerical calculations to obtain a solution. Nowadays, enough computer power is usually available for calculation of common problems.

Software groups focus on specialized problems and as a team they can provide high valued product which saves the time of the researcher. Software needs to be user friendly, easily controllable, able to multiphysical simulations, easy-to-do and illustrative graphical visualization of results. COMSOL Multiphysics fulfills these prerequisites. It is finite element based unifying multiphysical simulation environment. The COMSOL Multiphysics [11] simulation environment facilitates all steps in the modeling process - defining the geometry, specifying the physics, meshing, solving and then post-processing the results

4.1 Model-I

Hyperthermia is one of the most promising new multidisciplinary approaches to cancer therapy. The basic idea behind this treatment is to expose the body tissue at high temperature 43-45ºC, killing the malignant cell and damaging proteins and structures within cell, hyperthermia may shrink tumors. Microwave applicator suitable for hyperthermia needs to be properly designed in order to deliver electromagnetic energy into the tumor tissue with minimal irradiation of healthy tissue.

Geometry of the problem taken is drawn in CAD and imported to the COMSOL, [12] although it can be drawn in COMSOL itself. One of the advantages of COMSOL compared to other modeling software, even specialized on electromagnetics and radiof-requency modeling, is possibility to exploit axial symmetry of the problem. This enormously saves computer power and requirements on the memory by modeling in 2D instead of 3D. Geometry of the model is shown in the Figure 1.

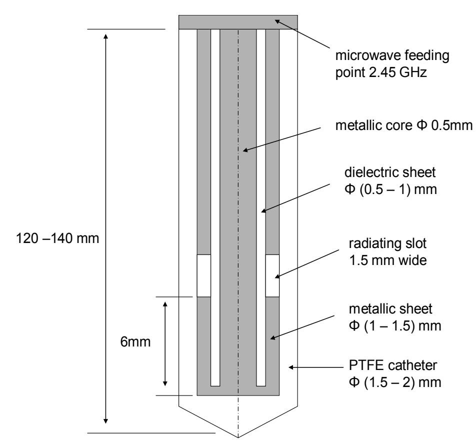

Figure.1. Single coaxial antenna with radiating slot

Finite Element Method has been applied for the modeling of one thin coaxial antenna inserted into the tissue. The antenna described in Figure 1. fed at 2.45 GHz, inserted in a volume of material with tissue properties is represented as a 3D Finite Element model. The tissue has the shape of a cylinder, coaxial with the antenna, with a radius of 30 mm, large enough to enclose the volume affected by the electromagnetic field source. The external surface of the cylinder acts as boundary for the computation domain. In the electromagnetic field problem, a low reflecting boundary condition is set on that surface, which means that the boundary does not disturb the electromagnetic field distribution, while in the heat transfer problem the boundary is thermally isolated. The microwave source is set at the upper end of the coaxial cable and the power emitted is adjusted to 1W.

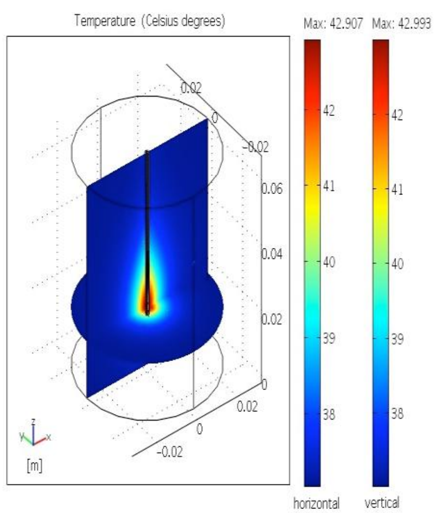

Figure.2. Temperature distribution in the tissue, 3D model

Figure.2 shows the temperature at the end of the heating process (the steady state) in longitudinal plane which include the symmetry axis of 3D model. Figure.3 shows the specific absorption ratio and temperature distributions computed with the 2D Finite Element Model, on the axis with maximal values, perpendicular to the antenna, at the upper end of the radiating slot. The penetration depth of the absorbed power is found to be 1.55 mm shown in Figure 4.

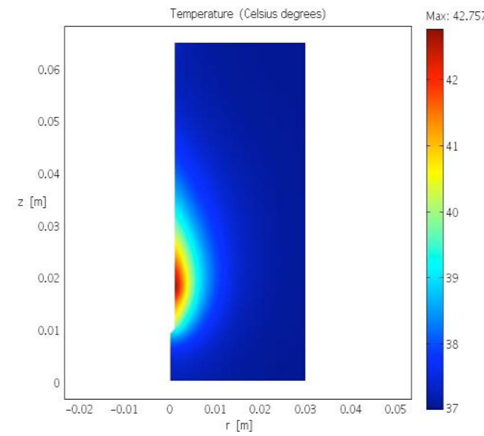

Figure.3. Temperature distribution in the tissue, 2D model

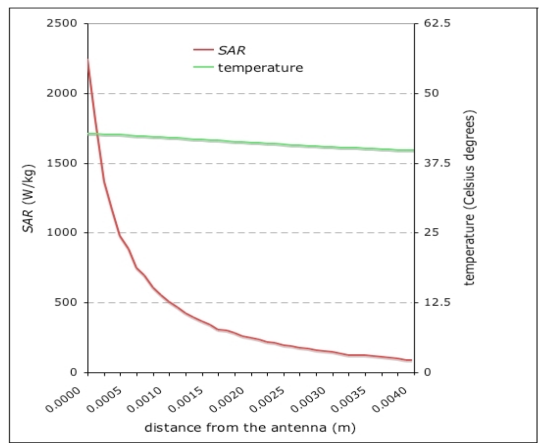

Figure.4 *SAR* and temperature decrease with the distance from the coaxial-slot antenna

5. Conclusion

An increasing use of the electromagnetic fields in medical applications. Modelling the electromagnetic field distribution in these devices will allow to design the optimized systems. On the other hand, a large number of equipment used everyday are electric or electronic ones, and thus generate electromagnetic fields. People are more and more concerned with the consequences of the exposure to the electromagnetic fields. Modelling the electromagnetic field distribution in the human body allows to provide a good answer to the worried persons. In both cases specific developments are required. We can see from the above discussion that several future aspect may be envisaged: link the electromagnetic phenomena into the cells to the electromagnetic properties values of the tissues, link the existing formulations to get accurate results on the whole frequency range, validate the electromagnetic-thermal coupling. Either we want to be protected from the fields, or we want to take benefit of the positive effects of these fields, all the effects thermal as well as genetic have to be well known. In both the cases the electromagnetic field distribution has to be computed in human body taking into account all the particularities of the system. The interaction between electromagnetic fields and biological tissue is one of the great challenges.

Hence Control of the interaction between electromagnetic fields and biological tissues is one of the challenges for the next years for which the COMSOL Multiphysics is integral part of this research.

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