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Original article

SOME ASPECTS OF MATHEMATICAL MODELING OF THE ELECTROMAGNETIC FIELD INFLUENCE ON THE HUMAN BRAIN

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Background. One of lacks of the use of high technologies is the megascopic level of unfavorable electromagnetic smog. Therefore, the study of influencing of the external electromagnetic field (EMF) is actual, within the limits of wide row of frequencies, on man's organs and brain.
Objective. Modeling of influences on the brain of electric induction arising up at penetration of the EMF of a different frequency in the reserved sphere.
Methods. A mathematical model of the EMF influence on human brain is considered. Namely, the model of a multi stratified sphere as an approximation of a human head is proposed. This sphere embedded into the unlimited nonconductive space ($\sigma_0 = 0$) of the dielectric constant ε_0. Skin and bones of head have a magnetic permeability of vacuum μ_0. Influences on a brain are given as induction of the electric field, arising up at penetration of the variable electromagnetic field in the reserved sphere.
Results. The results of numerical calculations for the three-layered model of head showed that induced of the electric field in the layer of brain has increased on the frequencies 10^7–10^8 Hz of external EMF. Distributions on the sphere of electromagnetic fields with $f \leq 10^6$ Hz leave their amplitudes by unchanged regardless of depth of penetration. Fading of amplitudes shows up only for frequencies 10^7 and 10^8 Hz.
Conclusions. Exposed in a model changes of electromagnetic waves on the frequencies 10^7–10^8 Hz can activate the parameters central nervous system and brain, that substantially will affect of man's activity. Will allow the further study of influencing of the electromagnetic field of a different frequency to identify to extent of brain activity, and also stress, positive and negative influencing of external EMF.

Keywords: mathematical model; penetration; electromagnetic field; human brain.

Introduction

One of the modern high-tech society features is an enhanced level of the electromagnetic unfavorable background known as the electromagnetic smog, which is one of the modern high-tech society disadvantages and the presence of such additionally induced electromagnetic fields within the broad range of frequencies must be taken into account since these different frequencies electromagnetic field background is quite typical for the environment. Its influence on a human organism, especially on the human brain, especially within a super high frequency (SHF) range (f = 15–750 MHz), is of immense scientific interest [1, 2].

Although this topic is being investigated for a longer time, there is the most harmful difficulty in the field studied. As far as the influence of super-high-frequency radiations on biological objects is concerned, no the unified approach is proposed to investigate this complicated problem yet. In spite of this fact, numerous theoretical and experimental case studies were carried out during the last decades as reviewed in [1, 3]. The results published make it possible to distinguish two principal classes of the electromagnetic SHF radiation effects on living organisms, namely thermal and non-thermal bioeffects. The thermal bioeffects are specified by heating of tissues when the enhanced temperature of 0.1 °C is indicated in the biological object studied due to the exposure of the SHF electromagnetic field characterized by the power amplitude of more than 10 mW/cm^2. Otherwise, the non-thermal effects are considered. While bioeffects due to the powerful SHF electromagnetic radiation influence has received the theoretical explanation and are consistent with experimental investigations, bioeffects induced by the low intensity SHF electromagnetic non-ionized radiation are still poorly understood being quite often not consistent enough or even contradictory and hardly replicated. As a result, the hypotheses on the physical mechanisms of influence of such radiation on the biological objects within the wide range of different evolution levels (from a one-celled organism up to a human) are still absent.

Usually, the scientific reports are focused on a cause-effect relationship, addressing versatile adverse health effects (e.g. cancer, CNS anomalies, endocrine and metabolic dysfunctions, blood and lymph illnesses etc.) induced by various sources of SHF non-ionized radiation as the radio equipment, radio-location sites, radars, telecommunicaion, wireless devices, Hi-Fi towers, power lines etc. As a matter of fact, electromagnetic waves are an important ecological factor and the investigation of bioeffects of the electromagnetic wave influence is the issue of the day, both for health protection and for the establishment of necessary hygienic norms to supply occupational safety.

In spite of lack of the universal approach to study SHF radiation bioeffects, the electromagnetic wave penetration into the human organism was investigated by many scientists and a number of approximations were proposed on the basis of electromagnetic field theory [4, 5]. For instance, the biological response approximated by the model of plane layers was studied. The frequency dependence of energy absorption for various combinations of plane layers was stressed [6]. This approach is used in a mathematical model presented below.

Materials and methods

Mathematical model. To study the influence of EM fields on the human brain a spherical model was chosen. From the physical point of view, the effect of the external electromagnetic background on the brain can be presented as penetration of electromagnetic waves into a human head considered as a stratified sphere. Its individual layers are characterized by different electrical conductivity σ_j and dielectric constant ε_j, where j reads for a given layer. The sphere is assumed to be surrounded by an unlimited space of electrical conductivity $\sigma_0 = 0$ and dielectric constant ε_0. The magnetic permeability is chosen to be equal to that of the vacuum (μ_0). The head along with its tissues and bones is assumed to be nonmagnetic. The model adopted allows to estimate the penetration of the external magnetic field into the head and to calculate the field attenuation using both the estimates of the magnetic field penetrated into the brain and electric field amplitudes induced. Taking into account that the sphere considered is rather small (the radius of the human head is about 15 cm) the external exciting field can be accepted to be homogeneous if EM waves are considered at $f < 300$ MHz (i.e. waves of a wavelength $\lambda > 1$ m are considered only).

The spherical model in the homogeneous oscillatory magnetic field is shown in Fig. 1. As seen, polar axis of spherical coordinates is parallel to the external magnetic field ${}^0\boldsymbol{H}$ which is accepted to be a time harmonic function described by $e^{i\omega t}$, where $\omega = 2\pi f$ is an angle frequency. This homogeneous field is of the colloidal type since a radial component ${}^0_r\boldsymbol{H}$ perpendicular to spherical concentric interfaces is not equal zero (Fig. 1).

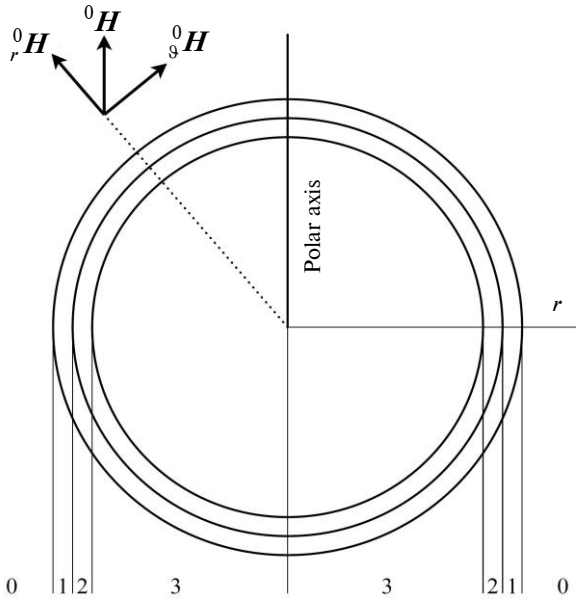

Figure 1: A three-layered spherical body as a model of a human head exposed to the homogeneous colloidal magnetic field ${}^0\boldsymbol{H}$

The classic theory of the EM field for spherical coordinates is used in calculations [6, 8]. Using Maxwell equations for the harmonic field the vector wave equation for the magnetic field $\boldsymbol{H}$ is:

$$\mathrm{rot}\boldsymbol{H}_j = k_j^2 \boldsymbol{H}_j, \qquad (1)$$

where $k_j^2 = \omega\varepsilon_j\mu_0 + i\omega\mu_0\sigma_j$ is a square of a complex wave number. The solution of this equation for a spherical model is well known as applied to its geophysical application [9]. Since the external exciting field is of the colloidal type its components are ${}^0_r\boldsymbol{H}$ and ${}^0_\vartheta\boldsymbol{H}$, the azimuthally component ${}^0_\Phi\boldsymbol{H}$ being zero identically (in fact the external field is axis symmetrical with regard to a polar axis). Meanwhile, the axis symmetrical magnetic field for individual layers ${}^j\boldsymbol{H}$ is described as a sum of spherical wave's ${}^0\boldsymbol{H}_n$ expressed by Legendre polynoms $P_n(\cos\vartheta)$ and radial functions $F_n(kr)$

and $Z_n(kr)$. As shown in [9], the magnetic field components are expressed as follows:

$$ {}^{j}_{r}\boldsymbol{H}_n = [{}^{j}A_n F_n(k_j r) + {}^{j}B_n Z_n(k_j r)] \frac{n(n+1)}{(k_j r)^2} P_n(\cos\vartheta), \quad (2) $$

$$ {}^{j}_{\vartheta}\boldsymbol{H}_n = [{}^{j}A_n F_n'(k_j r) + {}^{j}B_n Z_n'(k_j r)] \frac{1}{k_j r} \frac{dP_n(\cos\vartheta)}{d\vartheta}. \quad (3) $$

As known, the electric field $\boldsymbol{E}$ generated by $\boldsymbol{H}$ is described by the Maxwell equation as follows:

$$ \mathrm{rot}\boldsymbol{H} = (\sigma - i\omega\varepsilon)\boldsymbol{E}. \quad (4) $$

In case that the exciting magnetic field $\boldsymbol{H}$ is of the colloidal type (in other words, $\boldsymbol{H}$ is independent on the azimuthally coordinate φ), and keeping in mind the orthogonal of vectors $\boldsymbol{H}$ and $\boldsymbol{E}$, the electric field induced is described in spherical coordinates by the φ component only. Then based on (2) and (3) ${}^{j}_{\varphi}\boldsymbol{E}_n$ reads:

$$ {}^{j}_{\varphi}\boldsymbol{E}_n = \frac{1}{r(\sigma_j - i\omega\varepsilon_j)} [{}^{j}A_n F_n(k_j r) + {}^{j}B_n Z_n(k_j r)] \frac{dP_n(\cos\vartheta)}{d\vartheta}. \quad (5) $$

Results

Numerical calculations. The estimation of the magnetic field penetrated into the sphere and electric field induced in the brain by the exciting field is carried out, the spherical waves being expressed in terms of Legendre polynoms $P_n(\cos\vartheta)$ and radial functions $F_n(k_j r)$ and $Z_n(k_j r)$, where k_j is a wave number.

The numerical calculations of the EM field influence on the three-layered model for the frequencies f [Hz]: 0.1, 1, 5, 10, 10^2, 10^3, 10^4, 10^5, 10^6, 10^7, 10^8 are presented for the first harmonic $n = 1$.

The Eqs. (2), (3), and (5) applied for the three-layered spherical body (see Fig. 1) are used for numerical calculations. The external space ($j = 0$) is characterized by $k_0^2 = \omega^2\varepsilon_0\mu_0$ since $\sigma_0 = 0$. The individual layers are described in the Table, where σ_j and ε_j values are accepted according to [4, 7].

Table: Parameters of the three-layered spherical body used as a model of a human head

Layer identifier	Layer	Lower boundary of a layer r [cm]	σ_j [Ω^{-1} m]	Relative ε_j
0	Air	15.0	0.0	1.00
1	Hair, tissue	14.0	0.1	1.05
2	Skull	13.0	1.0	1.00
3	Brain	0.0	10.0	1.06

In the layer $j = 3$, where the inner sphere centre $r = 0$ is located, the coefficient ${}^{3}B_n$ (see [8]) is accepted to be zero since $Z_n(k_0 r)_{r=0} \to \infty$. In addition radial functions $F_n(k_j r)$ and $Z_n(k_j r)$ in [4] and [9] are defined using Hankel functions of the half integer index $(n+1/2)$. The frequencies f [Hz] are consequently considered in calculations:

0.1, 1, 5, 10, 100, 10^3, 10^4, 10^5, 10^6, 10^7, 10^8.

A spherical harmonic $n = 1$ is only considered in calculations. The distribution of $|{}_{r}\boldsymbol{H}_1|$, $|{}_{\vartheta}\boldsymbol{H}_1|$, and $|{}_{\varphi}\boldsymbol{H}_1|$ as functions of the radial distance from the surface of the sphere to its centre can be seen in Figs. 2–4. According to Fig. 2 magnetic field ${}_{r}\boldsymbol{H}_1$ and ${}_{\vartheta}\boldsymbol{H}_1$ reveals practically no attenuation in the head for $0.1 < f < 10^6$ Hz. Their values at $f = 10^6$ Hz are approximately without any change, the attenuation being too subtle at larger depths of the field penetration (Figs. 2 and 3, dashed line). This attenuation is apparent for $f > 1$ MHz as ${}_{r}\boldsymbol{H}_1$ and ${}_{\vartheta}\boldsymbol{H}_1$ plots for $f = 10^7$ Hz and $f = 10^8$ Hz show (Figs. 2 and 3).

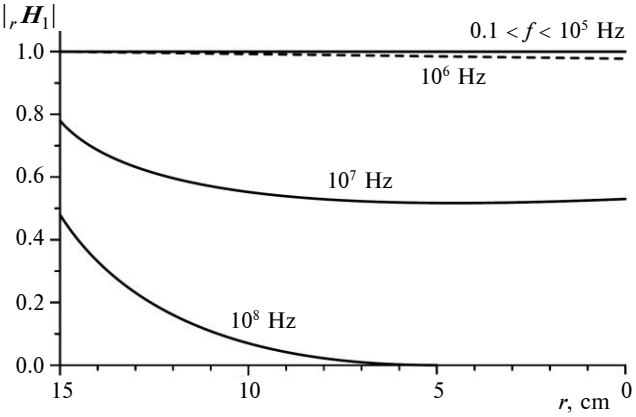

Figure 2: Distribution of the magnetic field module $|{}_{r}\boldsymbol{H}_1|$ in the spherical body from its surface up to its centre at frequencies considered [Hz]: $0.1 < f < 10^5$, 10^6, 10^7, and 10^8

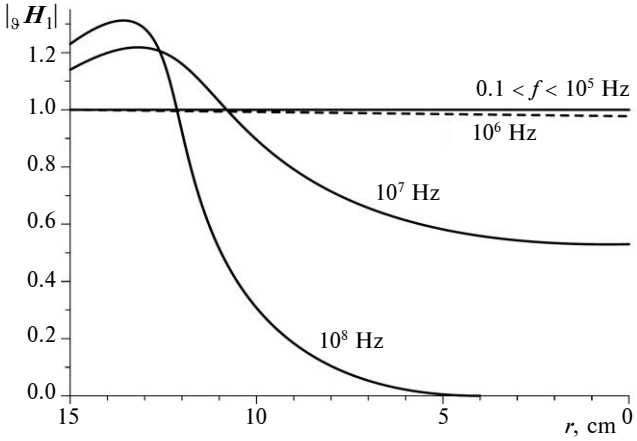

Figure 3: As in Fig. 2, but in case of $|_\vartheta E_1|$

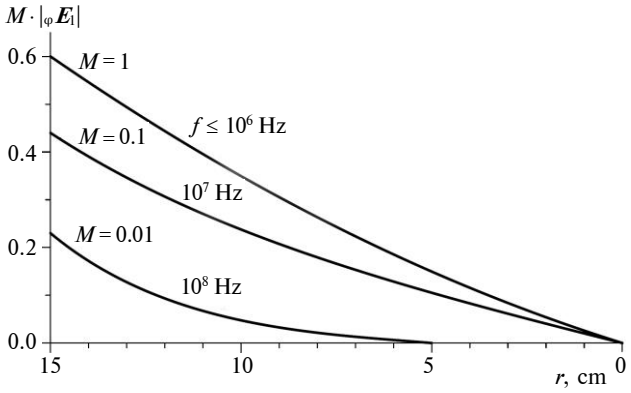

Figure 4: Distribution of the electric field intensity in the spherical body for the frequencies considered [Hz]: $f \le 10^6$, 10^7, and 10^8. Notice that the M values for the $f = 10^7$ and $f = 10^8$ curves are chosen to have $M \cdot f = 10^6$ in order to have the $M \cdot |_\varphi E_1|$ values of the same order as far as individual frequencies are concerned

Discussion

Due to the oscillatory colloidal magnetic field ${}^0H_1$ the electric field ${}_\varphi E_1$ is induced in the spherical body. Its intensity does significantly depend on the frequency given and enhances with the increasing f [7]. To display the corresponding plots the electric field values are modified using a proper multiplication M to satisfy $M \cdot f = 10^6$, which allows to have the $M \cdot |_\varphi E_1|$ values of the same order as far as individual frequencies are concerned. As seen in Fig. 4, for $f \le 10^6$ Hz the electric field intensity in the sphere decreases quite linearly in the direction to its centre. The exponential decrease of the electric field amplitude with the depth takes place for $f = 10^8$ Hz, which leads to the so-called skin effect (Fig. 4).

According to the calculated plots of the distribution of field components, those for $f < 10^6$ Hz keep their amplitudes unchanged regardless of the depth of penetration. The attenuation of component amplitudes is apparent only for frequencies 10^7 and 10^8 Hz. The electric field induced increases with the increasing frequency of the external field. On the other hand, at $f \le 10^6$ Hz, the electric field amplitude generated decreases linearly with depth, while the field amplitude for $f = 10^8$ Hz reveals the exponential decrease with depth, i.e. the so-called skin effect takes place.

The EM field influence at $f > 10^6$ Hz demonstrating an apparent attenuation results in thermal effects (Joule heating), which are harmful to head tissues (i.e. proper conditions of biosecurity in the vicinity of radars are of importance).

Conclusions

The spherical three-layered model (approximation of a human head) exposed to the homogeneous oscillatory magnetic field of the colloidal type is considered. Numerical calculations show that EM field influence is a function of frequency exposed. At frequencies $f < 10^6$ Hz the magnetic field penetration into the head is practically unchanged which is a physical basis for a plausible effect on the CNS and consequently on decision-making man's activities. On the other hand, the apparent EM field attenuation characteristic for $f \ge 10^7$ Hz indicates that the penetrated field may be harmful to tissues due to Joule heating effects. The plausible different channels of the EM field influence on the human brain need research efforts on the interdisciplinary basis [2].

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ДЕЯКІ АСПЕКТИ МАТЕМАТИЧНОГО МОДЕЛЮВАННЯ ВПЛИВУ ЕЛЕКТРОМАГНІТНИХ ПОЛІВ НА МОЗОК ЛЮДИНИ

Проблематика. Одним із недоліків використання високих технологій є збільшення рівня несприятливого електромагнітного смогу. Тому актуальним є вивчення впливу зовнішнього електромагнітного поля (ЕМП), у межах широкого ряду частот, на органи та мозок людини.
Мета. Моделювання впливу на мозок електричної індукції, яка виникає при проникненні ЕМП різної частоти в замкнену сферу.
Методика реалізації. Математична модель впливу ЕМП на мозок людини розглянута в наближенні до моделі голови людини у вигляді декількох замкнутих у коло шарів, що мають різні електричну провідність і діелектричну константу. Ця замкнута сфера оточена непровідним нескінченним простором ($\sigma_0 = 0$) з діелектричною константою ε_0. Шкіра і кістки голови мають магнітну проникність вакууму μ_0. Впливи на мозок подаються як індукція електричного поля, що виникає при проникненні змінного електромагнітного поля в замкнену сферу.
Результати. Отримані результати цифрових обчислень для тришарової моделі голови показали, що індукція електричного поля в шарі мозку зростала на частотах 10^7–10^8 Гц зовнішнього ЕМП. Поширення у сфері електромагнітних полів з $f \le 10^6$ Гц залишає їх амплітуди незміненими незалежно від глибини проникнення. Затухання амплітуд виявляється тільки для частот 10^7 і 10^8 Гц.
Висновки. Виявлені в моделі зміни електромагнітних хвиль на частотах 10^7–10^8 Гц можуть активувати параметри центральної нервової системи та мозку, що суттєво вплине на активність людини. Подальше вивчення впливу електромагнітних полів різної частоти дасть можливість ідентифікувати ступінь активації мозку, а також стресові, позитивні та негативні впливи зовнішнього ЕМП.

Ключові слова: математична модель; проникнення; електромагнітне поле; мозок людини.

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НЕКОТОРЫЕ АСПЕКТЫ МАТЕМАТИЧЕСКОГО МОДЕЛИРОВАНИЯ ВЛИЯНИЯ ЭЛЕКТРОМАГНИТНЫХ ПОЛЕЙ НА МОЗГ ЧЕЛОВЕКА

Проблематика. Одним из недостатков использования высоких технологий является увеличение уровня неблагоприятного электромагнитного смога. Поэтому актуально изучение влияния внешнего электромагнитного поля (ЭМП), в пределах широкого ряда частот, на органы и мозг человека.
Цель. Моделирование влияния на мозг электрической индукции, возникающей при проникновении ЭМП разной частоты в замкнутую сферу.
Методика реализации. Математическая модель влияния ЭМП на мозг человека рассмотрена в приближении к модели головы человека в виде нескольких замкнутых в круг слоев, обладающих разными электрической проводимостью и диэлектрической константой. Эта замкнутая сфера окружена непроводящим бесконечным пространством ($\sigma_0 = 0$) с диэлектрической константой ε_0. Кожа и кости головы имеют магнитную проницаемость вакуума μ_0. Влияния на мозг представляются как индукция электрического поля, возникающая при проникновении переменного электромагнитного поля в замкнутую сферу.
Результаты. Полученные результаты цифровых вычислений для трехслойной модели головы показали, что индуцирование электрического поля в слое мозга возрастало на частотах 10^7–10^8 Гц внешнего ЭМП. Распространение в сфере электромагнитных полей с $f \le 10^6$ Гц оставляет их амплитуды неизмененными независимо от глубины проникновения. Затухание амплитуд проявляется только для частот 10^7 и 10^8 Гц.
Выводы. Выявленные в модели изменения электромагнитных волн на частотах 10^7–10^8 Гц могут активировать параметры центральной нервной системы и мозга, что существенно повлияет на активность человека. Дальнейшее изучение влияния электромагнитного поля разной частоты позволит идентифицировать степень активности мозга, а также срессовые, положительные и негативные влияния внешнего ЭМП.

Ключевые слова: математическая модель; проникновение; электромагнитное поле; мозг человека.