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SPECIFIC CONDITIONS FOR EMF MODELING IN HUMAN EXPOSURE FROM MOBILE PHONE TECHNOLOGY

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Abstract. *The development of telecommunications has been followed by research concerning the effects of microwave frequency electromagnetic fields on biological systems. The highly-complex physical and biological phenomena involve experimental, measuring, computation and observation procedures, and it is still difficult to draw clear conclusions, in spite of the enormous volume of scientific work already performed in that domain. Numerical modeling of the electromagnetic field problem is an engineering approach to this subject. This paper describes characteristics of sources and electric properties of the anatomical tissues, necessary to evaluate electromagnetic field penetration in human body exposed to microwave radiation, in specific conditions from mobile phone technology.*

ELECTROMAGNETIC FIELD EMISSION FROM MOBILE PHONE TECHNOLOGY

Mobile phones are defined as low power radio devices that transmit and receive microwave radiation. In Europe (including Romania) they operate at frequencies of around 900 MHz and 1800 MHz (Global System for Mobile Communications - GSM) and for the near future the operation in the 1885-2010 and 2110-2200 MHz bands is expected for the Universal Mobile Telecommunication System - UMTS.

Output from mobile phones

Cellular radio systems involve communication between mobile telephones and fixed base stations, that provides coverage of a given area, termed a cell. Each cell is formed around a base station. In the GSM system, each user requires a frequency channel of 200 kHz bandwidth. Within the 35 MHz bandwidth of the 900 MHz band there is a maximum of 175 channels and within the 75 MHz bandwidth of the 1800 MHz band there is a maximum of 375 channels; one channel is used for technical reasons. The channels are distributed across the cells in a way that avoids interference: neighboring cells operate at different frequencies.

GSM system is associated with a technique called Time Division Multiple Access - TDMA, that permits each channel to be simultaneously used by eight phones; the information from each user is transmitted in compact packages of 0.58 ms every 4.64 ms (which results in a 1/0.00464 = 216 Hz pulse modulation); this transmission allows the decrease of the total amount of energy emitted by a cellular phone during a phone call. The maximum powers that GSM mobile phones are permitted to transmit (by the present fabrication standards) are 2W for 900 MHz and 1W for 1800 MHz. However, because TDMA is used, the average power transmitted by a single phone is less than one-eighth of the maximum value.

This power is further reduced by the other technical characteristics of the system, such as adaptive power control and discontinuous transmission. Adaptive power control means that the phone continually adjust the power it transmits to the minimum needed for the base station to receive a clear signal. Discontinuous transmission refers to the fact that the power of the phone is switched off when the user stops speaking and he is listening. Depending on the location of the mobile phone user inside a certain cell, the transmitted power usually varies between 0.05 W and 1-2 W, but rarely it is maintained for long time at its maximum levels.

The microwave power from a mobile phone is mainly transmitted by the antenna, together with electronic elements inside the handset. The antenna is usually a metal helix or rod, a few centimeters long and could be considered a dipole antenna. The user is exposed (with the head and ear) at a distance of 2-3 cm, in the near-field of the antenna (the near-field is within a few wavelengths, and at 1800MHz, the wavelength is 16.7 cm). In the near-field region an antenna effect occurs, and the net radiated energy of the wave is augmented by an oscillating energy that flows along the direction of the antenna (figure 1). The electric field and magnetic flux density estimated (calculated in free space, around the antenna) at 2 cm distance of the antenna are about 400 V/m and 1 μT for a 2 W and 900 MHz cell phone, and about 200 V/m and 1 μT for a 1 W and 1800 MHz cell phone; the power density at the same distance is for both phones around the value of 200 W/m^2. Additionally, there is a magnetic field component of a few μT, and 216 Hz, generated by currents flowing from the battery, which are switched on/off at this frequency, in order to synchronize the discontinuous transmission facility with the TDMA system.

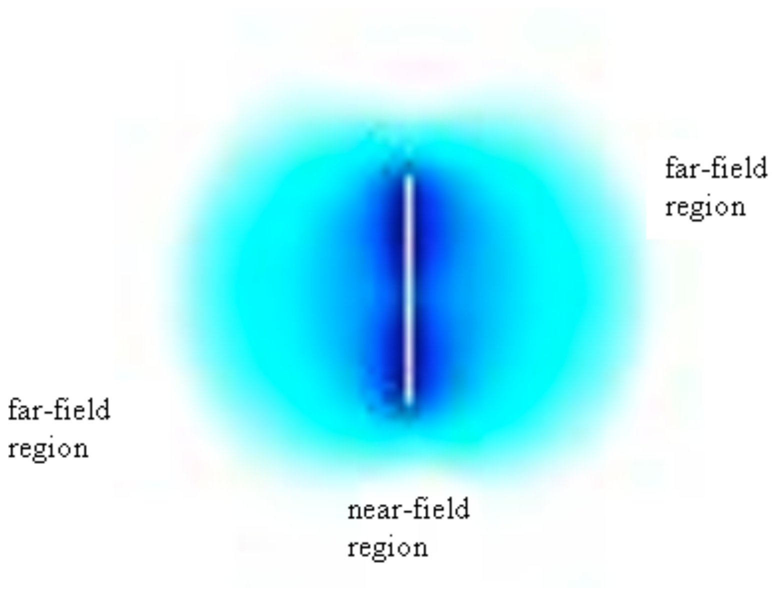


Figure 1 Radiated energy from a dipole antenna

When the exposed head is near the antenna, the electromagnetic field distribution is disturbed due to the electric properties of the tissues. This is the reason for an accurate numerical modeling of the human head exposed to specific microwave radiation.

Output from base stations

Besides the exposure of the users in the near-field region of their mobile phone antenna and handset, the mobile phone technology produces microwave radiation exposure from the base stations antennas. These antennas are mounted on towers, or they are placed on top or attached to the side of high buildings. A large proportion of the radiated power is focused into a conical beam, typically about 6^o wide, slightly inclined from the horizontal and directed to the earth; usually it does reach ground level at a distance between 50 and 200 m from the tower or building base (figure 2). Around the main beam there is a series of weak beams (side lobes), with lower energy.

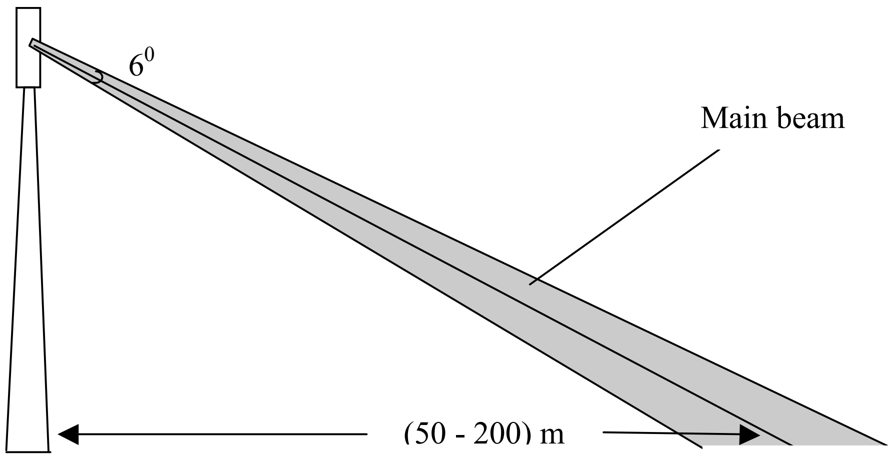


Figure 2 The main beam of radiation from a base station antenna

The base station antennas emit far greater power than the individual mobile phones antennas in order to avoid electromagnetic interference inside the cell. The limit of the transmitted power is set to the maximum Equivalent Isotropically Transmitted Power - EIRP, which is the power that would have to be emitted equally in all directions to produce the maximum permitted power density. However, as figure 2 shows, the emitted radiation is not isotropic, with most of the power emitted into the main beam. The ratio of the EIRP to the total power output is called the gain of the antenna, which is very much dependent of the configuration and position of the antenna. The gain is usually between 40 and 60, and the limit sets by communication and environmental authorities for EIRP is 1500 W per frequency channel. This lead to a maximum radiated power of about 30 W per communication channel.

In practice, one could find a number of less than 4 channels for a base station, which means that the maximum power radiated by a base station antenna is less than 120 W (typically 60 W). By the inverse square law, the radiated power density at the ground, at 50 m from a 10 m tower carrying an antenna transmitting 60 W is about 100 mW/m^2; this corresponds (in free space) to an electric field of 5 V/m, and a magnetic flux density of 0.02 μT. As one could see, the values are two orders of magnitude smaller than those estimated in the near-field of a cell phone antenna. The exposure of a person on the street, around a base station, is far less important than the exposure of a mobile phone user. However, the exposure for the maintenance workers, who approach very much the antenna of the base station, could be appreciably larger.

ELECTRIC PROPERTIES OF ANATOMICAL TISSUES

Dosimetric investigation on human exposure to microwave radiation

Dosimetry is "the metrology of dose". Dose is defined by the amount of a substance or the energy, a body is exposed to, or come in contact with. It is a scientific consensus to consider, in high frequency electromagnetic field exposure, that thermal effects prevail and the Specific (Energy) Absorption Rate (SAR) is the quantity that represents the "dose" at frequencies from 100 kHz to about 10 GHz. SAR [W/kg] is defined, at a macroscopic scale, as the absorbed power per unit mass at infinitesimal volume of tissue. The rate at which the energy is absorbed by a particular mass of tissue, m, is ($m\sigma E^2/\rho$), where σ is the electric conductivity and ρ is the density of the tissue; E represents the electric field (rms value). Consequently, ($\sigma E^2/\rho$) is the "specific energy absorption rate", usually called SAR. Its distribution in the body is inhomogeneous, both because the electric field changes with position and because the conductivity is different for different types of tissue. Unlike the conductivity, the density has low changes amongst different types of tissue.

At microwave frequency the penetration depth of the electromagnetic field inside the tissue is very small* and the exposure is localized in the head and ear region in the proximity of the handheld telephone. However, in microwave frequency exposure, other than thermal effects could occur, and the numerical estimation of electromagnetic field distribution inside de body is very useful because the problem moves to microdosimetry (dosimetry at cellular level).

Electrical conductivity and permittivity

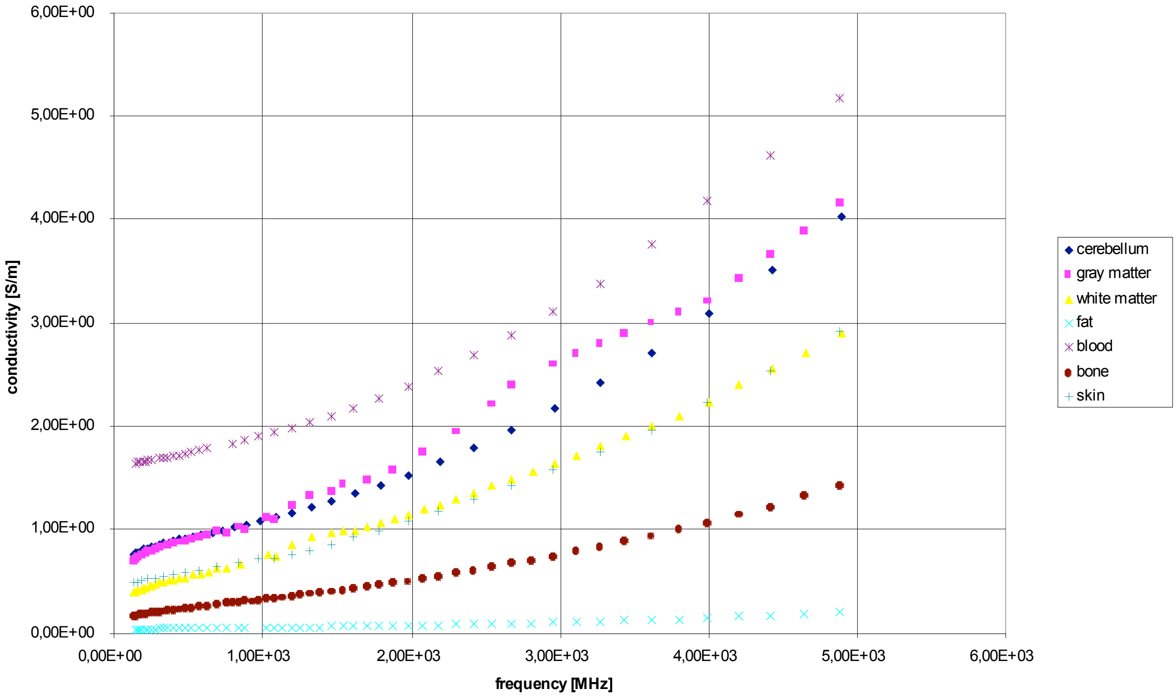
The interaction of the electromagnetic field at microwave frequencies is usually described in terms of the *complex permittivity* $\underline{\varepsilon} = \varepsilon - j\sigma/\omega$, or the *complex conductivity* $\underline{\sigma} = \sigma + j\omega\varepsilon$ (it is obvious that $\underline{\sigma} = j\omega\underline{\varepsilon}$), where ε is the electric permittivity (or the dielectric constant of the material), σ is the electric conductivity, $\omega = 2\pi f$ and $j = \sqrt{-1}$. The reason is that the biological tissues in this frequency range act as conductive dielectric materials, i.e. both the real and imaginary parts of the complex permittivity/conductivity are of the same order of magnitude and have equally weight in the electromagnetic field equations. Table 1 presents a set of experimental data, commonly assigned to these properties at microwave frequencies.

Table 1 Electric properties of selected tissue at microwave frequencies [9]

tissue → freq. [MHz]↓		skeletal muscle	myocardium	liver	kidney	lung	fat	spinal cord
$\mathrm{Re}\{\underline{\sigma}\} = \sigma$ [S/m]	400	1.11-1.18	1-1.18	0.77-0.95	1.18	0.714	0.04-0.11	
	700	1.27-1.37	1.05-1.28	0.87-1.18	0.13	0.769		
	1000	1.27-1.33		0.94-1.02			0.08-0.15	0.04-0.1
	3000	2.17-2.33		2-2.04			0.11-0.23	0.12-0.23
	8500	8.33		5.9-6.7			0.27-0.42	0.17-0.47
$\mathrm{Im}\{\underline{\sigma}\} = \omega\varepsilon$ [S/m]	400	1.16-1.2	1.16-1.3	0.98-1.13	1.18-1.22	0.78	0.09-0.16	
	700	2.02-2.06	1.9-2.14	1.63-1.98	1.94-2.06	1.32		
	1000	2.72-2.89		2.56-2.67			0.3-0.42	0.24-0.41
	3000	7.5-8		7-7.17			0.65-1.2	0.7-0.83
	8500	18.9-19.8		16-17.95			1.65-2.13	2.08-2.55

An extensive experimental and theoretical study was performed by C. Gabriel [8] based on multiple measurements on human and animal tissues, and a comprehensive data base is generated. A selection of data in the microwave frequency range was performed for the present study; figure 3 shows electric conductivity and relative dielectric permittivity, for several anatomical tissues from the head region.

* The penetration depth in a conductive semiinfinite space is defined as $\delta = \sqrt{1/\pi\mu f\sigma}$, where μ is the magnetic permeability, f is the frequency and σ is the electric conductivity. For biological tissue, $\mu = \mu_0 = 4\pi 10^{-7}$ H/m and $\sigma \approx 1$ S/m, and for GSM system frequency bands, results δ = (12 - 17) mm.



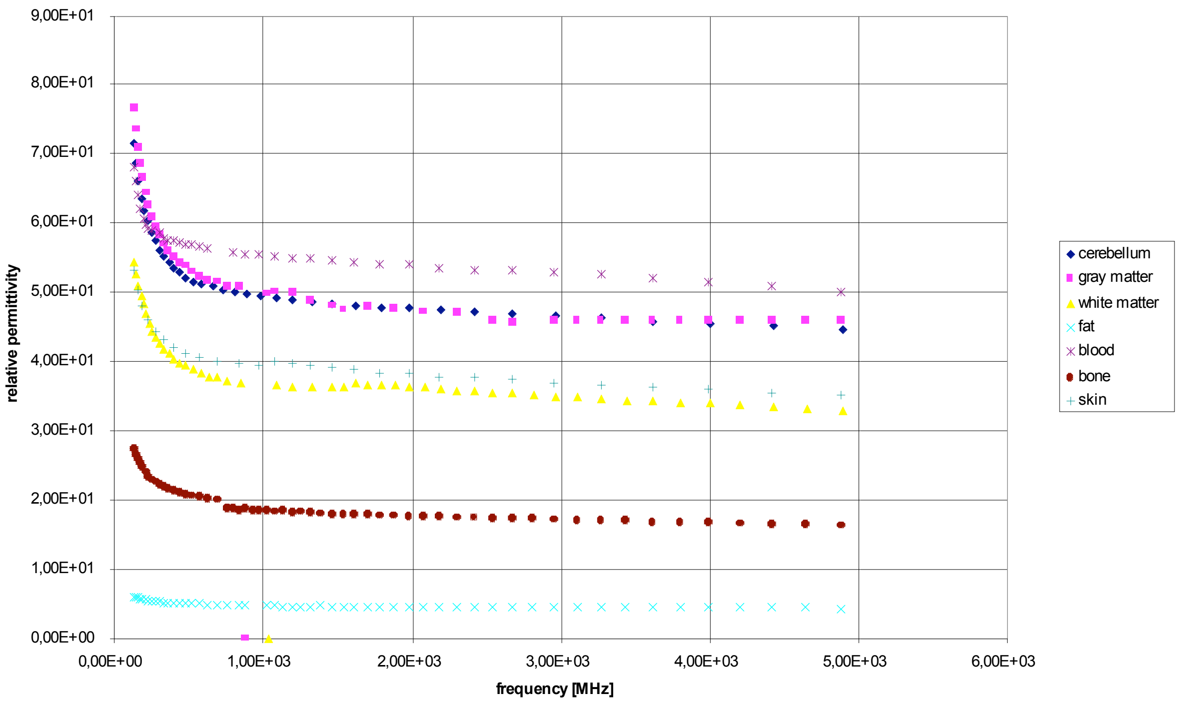


Figure 3 Electric conductivity and relative permittivity in the microwave frequency range

POTENTIAL HEALTH HAZARD AND EXPOSURE GUIDELINES

The use of mobile phones is developing rapidly. In many European countries, over half the population already uses mobile phones and the industry predicts that there will be as many as 1.6 billion worldwide mobile phone subscribers in the year 2005.

Some uncertainty, about the health effects of radiofrequency fields (microwaves) which mobile phones and their base stations emit, persists amongst the scientific community, public health organizations (like World Health Organization) and the general public. Consequently, there is a consensus that exposure guidelines for microwaves should be set to prevent adverse health effects caused by either whole or partial body exposure. Some of the energy in the electromagnetic waves emitted by mobile phones is absorbed in the head of the user, mostly in superficial tissues. The direct effect is the heating of the exposed tissue, but the temperature rise is negligible in the usual exposure conditions.

Concerns about other possible, so-called non-thermal, effects have also been raised. Scientific data indicate, with relative certainty, that, during exposure to radiation from a mobile phone, a variety of biological effects occur (e.g. electroencephalogram profile, reaction time, etc.) at energy levels that do not cause any local increase in temperature. These include suggestions of subtle effects on cells that could have influences on electrically excitable tissue (especially the brain and sensorial tissue). Radio waves do not have sufficient energy to directly damage genetic material (DNA) in cells and cannot therefore cause cancer. There have been suggestions that they may be able to influence cancer promotion or progression. However, there is no human evidence of a risk of cancer resulting from exposure to radiations that arise from mobile phones. There has also been concern about whether there could be effects on brain function, with particular emphasis on headaches and memory loss, but these possibilities are vaguely investigated. Recently, delayed effects on the central nervous system have been reported in epidemiological studies, but this type of effects require long time observation and repetitive investigation. A lot of biological research was conducted on this subject, but the evidence does not suggest the existence of an obvious health hazard. The lack of evidence does not, however, prove the absence of a risk and more specific research is encouraged by the scientific and socio-political forums.

Exposure guidelines relevant to mobile phones are expressed in terms of absorbed energy in a small mass of tissue (primarily in the head). The international forum recognized as the main authority in tracing guidelines for non-ionizing electromagnetic field exposure is ICNIRP (International Commission on Non-Ionizing Radiation Protection) that issued in 1998 a comprehensive material [1] adopted by the majority of national standardization authorities in countries were the mobile telephony is in progress; the European Commission issued in 1999 a document of recommendation for the ICNIRP guidelines [2] and several national and international research and dissemination programs have the objective of analyzing and promoting exposure guidelines in order to avoid any suspected health adverse effect.

In the development of its guidelines, the approach used by ICNIRP refers to establishing *basic restrictions* (limitation of current density, specific absorption rate and/or power density inside the exposed body) and *reference levels* of exposure (limitation of incident electromagnetic field parameters) and states that compliance with the reference levels will ensure compliance with the relevant basic restrictions.

The basic restriction for occupational exposure to radio frequency radiation (frequencies between 100 kHz and 10 GHz) is 0.4 W/kg for whole body specific energy absorption rate (SAR). For exposures of the general public, a reduction factor of five is applied, resulting in a basic restriction on whole body SAR of 0.08 W/kg. The factor of five reduction also applies to the basic restriction on localized SAR (head and body), the values for those occupationally exposed and for the general public being 10 W/ kg and respectively 2 W/kg, averaged over any 10 g of tissue.

Basic restrictions are intended to limit whole and partial body heating. The basic restrictions on whole body SAR for occupational exposure are accepted by ICNIRP as providing a large margin of safety for other limiting conditions such as high ambient temperature, humidity, or level of physical activity. The restrictions are, therefore, assumed to provide an adequate level of protection for all exposed individuals under all working conditions and thus can be considered highly conservative. The reductions in SAR for the general public are explained by ICNIRP on the basis that the age and health status of members of the general public, and hence their sensitivity to thermal challenge, may be different from those of professionals trained to work in electromagnetic field exposure.

The microwaves produced by transmitters used in base stations are sufficiently weak that the guidelines can only be exceeded for an exposure within a few meters directly in front of the antennas. Microwave strengths at ground level and in regions normally accessible to the public are many times below hazard levels and no heating effect could possibly be detected.

CONCLUSIONS

The numerical modeling of specific electromagnetic field penetration in human body and its distribution in anatomical tissue is a valuable tool for the bio-medical investigation of physiologic phenomena associated to microwave radiation exposure. Electromagnetic measurements inside the exposed body are hardly difficult to perform, both because the discomfort caused to the subject by the implantable sensors and because the electromagnetic interference between the source of the field and the measuring devices. Numerical modeling eliminates these inconveniences and could offer precise values of electromagnetic field parameters at different locations inside the body.

The paper investigates two categories of data necessary for the formulation of the numerical model:

* the source - a quantitative description of the electromagnetic field regime and parameters in mobile phone technology,
* the material properties - analyze of electric properties of anatomical tissues in the frequency bands specific to mobile telephony.

Research in the field of health effects of microwave exposure due to mobile phone technology is currently under progress, and is encouraged by international scientific community and important organizations in the socio-economic domain, in health and in mass media. It is expected that the trend in the future research on this topic will emphasize the physical and engineering aspects in the qualitative and quantitative evaluation of medical and biological aspects, in order to reduce the uncertainties that exist in unsolved problems of electromagnetic field health issue.

The work presented here is performed as the first step in solving the problem of electromagnetic field modeling in conditions specific to mobile phone technology, and is the introductory part to a larger study, under the CNCSIS research grant nr. 345/2002.

References

[1] Guidelines for limiting exposure to time-varying electric, magnetic and electromagnetic fields (up to 300 GHz). Health Phys., 74, No. 4, 494–522 (1998).
[2] Council Recommendation of 12 July 1999 on the limitation of exposure of the general public to electromagnetic fields (0 Hz to 300 GHz). Document 1999/519/EC.
[3] IEGMP (2000) Independent Expert Group on Mobile Phones, Mobile Phones and Health, National Radiological Protection Board, UK, 2000.
[4] Les téléphones mobiles, leurs stations de base et la santé. Rapport au Directeur Général de la Santé, France, 2001.
[5] Buletinul Asociatiei pentru Compatibilitate Electromagnetica din Romania - ACER, nr. 8, 2002
[6] Nicolaescu St., V. - "GSM, a support for developing of UMTS", International Symposium on Signals, Circuits and Systems, Iasi 1999.
[7] Nicolaescu St. V. , Petrescu T. - "Trends in mobile terrestrial communications for the next years", International Conference on Communications, Bucuresti, 1998.
[8] Camelia Gabriel, Sami Gabriel - "Dielectric Properties of Body Tissues at RF and Microwave Frequencies", Report for Armstrong Laboratory (AFMC), Occupational and Environmental Health Directorate - Radiofrequency Radiation Division, USA, 2002
[9] Polk Ch., Postow E. eds. - "CRC Handbook of Biological Effects of EM Fields", CRC Press Inc., 1986