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Dosimetric Quantity System for Electromagnetic Fields Bioeffects

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ABSTRACT

Dosimetric evaluation system used is able to determine the distribution of SAR (Specific Absorption Rate) inside a phantom model that complies with European and USA standards (EN 50361, IEEE 1528). It consists of a robot, an electric field probe calibrated for use in liquids, a ghost "twin" ghost "elliptical flat" fluid simulation of human tissue, a gripping device DUT (device under test) and software Open SAR. Specific Absorption Rate (or SAR) is a measure of how transmitted RF energy is absorbed by human tissue. SAR is a function of the electrical conductivity, the induced E-field from the radiated energy (measured in Volts/meter) and the mass density of the tissue. Due to the high sensitivity of the probe, its output voltage is measured without amplification. Electric field probe corresponds to the recommendations of CENELEC (European Committee for the Coordination of Electrical Standards) and IEEE (Committee of Electrical and Electronic Engineers in the field) for measuring electromagnetic fields of mobile phones, base stations and radiating devices. DUT latch is constructed of a material with low loss and low permittivity. It allows moving the axes Ox, Oy, Oz or rotation around phantom ear for precise positioning of the DUT. With the software robot motion control Open SAR, local SAR values are determined and calculated SAR values averaged over 10 grams and 1 gram of tissue.

1. Introduction

Lately the public has increasingly begun to put in various forms, whether electromagnetic radiations are harmful or not. While there are all sorts of answers, nobody could establish with certainty whether on the long run the the answer is negative. In the short term, there is an official view of the World Health Organization who was involved in this research and set exposure limits for public safety. Researches performed by committees set up for this purpose has led to defining a legal framework adopted by most countries. Increased population concern has led to a mass psychosis and assimilation into the urban culture of the radiation legend. The ideas circulating are fueled by the media who prefer alarming topics for potential audience, although ironically much of it makes full use of electromagnetic waves from negligible levels of radiation. The urban culture was unconvincing countered by the authorities, which led to the undermining of confidence in them. In Romania, the public health enemy is usually identified as a GSM operator (population does not distinguish compared to CDMA systems), and the alleged danger is the possibility of contracting cancer. This belief is due to confusion with ionizing radiation because usually the public does not distinguish between them.

The population protection against the possible consequences of ionizing radiation is a legitimate goal that must preoccupy any regulatory authority for telecommunications. Protection should be done within the legal framework, without exceeding his authority and should be effective. At present there is no clear control location of base stations on their ability to achieve power densities, pedestrian or residential areas. Therefore, before before practicing regulatory and protection action it must be cleared the legislation purpose. There are several ways to appreciate the dosimetry of ionizing radiation. One is SAR (specific absorption rate) which is measured in W/kg and is a measure of RF power absorption in living tissue. SAR is the most direct expression of biological and thermal effect is a measure of the notified body. Returning to the duality of cause and effect, SAR is a measure of the effect. This is not only dangerous side effects with the potential biological hazard and other effects on different frequencies (with electric currents are induced or undesirable effects on the central nervous system). Therefore, there is a quantization of electric and magnetic field strength and power density. In this regard it has been established reference levels, which limits exposure and guaranteeing that biological effects are undesirable.

Current regulations on exposure, such as those issued by ICNIRP (International Commission on Non-Ionizing Radiation Protection) protects against these effects. Pressing problem is the likelihood of the occurrence health effects at exposure levels below the reference levels and in particular the effects that can occur on long exposure to low levels of electromagnetic field. In table 1 we have illustrated some typical sources of electromagnetic field.

Table 1:- Some typical sources of electromagnetic field.

Frequency range	Frequency	Source field	Maximum intensity of the field
Static electromagnetic field	0 Hz	Natural Video terminals Magnetic resonance imaging (MRI) and other scientific or diagnostic instruments Industrial electrolysis	70 µT 1 T inside the tunnel 200 mT at the entrance into the tunnel ≤0,5 mT outside the measurement chamber 10-30 mT at the legs level
Low frequency electromagnetic field	0-300 Hz	Electric power lines Indoor distribution lines Trains and tramways electric motors	10-20 µT under the line - 10 KV/m ≤ 0,2 µT inside 50 µT , 300 V/m

Intermediate frequency electromagnetic field	300 Hz-100 kHz	Video terminals Anti theft resources Hands free access control system Card readers and metal detectors	30-70 nT 10 V/m
High frequency electromagnetic field	100 kHz-300 GHz	Radio transmitters and television, cellular phone. Microwave ovens Radar, radio transmitters fixed and mobile, portable radio stations.	0.1 W/m 0.5 W/m 0.2 W/m

The dielectric properties of the fluid for simulating the human tissue are measured before measuring the Specific Absorption Rate at the same temperature. The measured quantities are electrical permittivity ε and conductivity σ and their measured values must match the tolerance of ± 5% compared to the values specified in the standard. Before measuring the SAR tested product, we check if the dosimetric evaluation system works according to specifications. For the SAR measurements we used a scheme where the signal comes from a generator and is issued with a dipole antenna. Components and measurement procedures for verifying performance are the same as those used for compliance testing. The result of this verification must be within ± 10% of the value determined during the validation check of the system.

The device under test was charged with internal antenna (s), battery and accessories supplied by the manufacturer. The battery was fully charged before each test and there were no external connections to it. The output power and frequency were controlled by a base station simulator. For each position of the product they have the following steps:

- establish a radio connection to the DUT at maximum power with the base station simulator;
- measuring SAR values a network of equidistant points on a surface located at a constant distance from the inner surface of the phantom;
- measuring SAR values in equidistant points in a cube;
- calculating the SAR average value of the measured data and comparing it to the limit.

2. Guidelines for limiting public exposure to electromagnetic fields

In 1999 the Council of the European Union gave the need to protect people against the harmful effects that may result from exposure to electromagnetic fields, has issued the recommendation 1999/519/EC for limiting the public exposure to electromagnetic fields (0 Hz to 300 GHz). One of the principles covered by this recommendation is that the basic restrictions and reference levels for limiting exposure have been developed taking into account all the results published in the dedicated scientific literature. Were taken safety factors 50 times better than the basic limits to development restrictions thus covering the recommendation regarding possible long-term effects from the entire frequency spectrum. International Commission on Non-Ionizing Radiation Protection endorsed this recommendation which has become a reference document for all EU Member States.

Restrictions on exposure to time-varying electric, magnetic and electromagnetic fields which are based directly on health effects and proven biological considerations are defined as basic restrictions. Depending on the frequency of the field, the physical quantities used to describe these restrictions are magnetic flux density (B), current density (J), specific absorption rate (SAR) and power density (S). Magnetic flux density and power density can be measured directly in case of exposed people.

The reference levels are established for practical exposure assessment purposes, to determine if there is a risk of exceeding the basic restrictions. Some reference levels are derived from relevant basic restrictions using measurements and / or calculation methods, and other benchmarks relate to perception and indirect harmful effects of exposure to electromagnetic fields. The sizes are derived electric field (E), magnetic field strength (H), magnetic flux density (B), power density (S) and Limb induced current (I). The quantities relating to perception and other indirect effects are contact current (Ic) and pulsed fields, specific absorption (SA) energy. If a particular exposure, measured or calculated values of these quantities can be compared with the appropriate reference level. Compliance with the reference level ensures proper compliance with basic restrictions. If the measured value is higher than the benchmark, not necessarily follow that the basic restriction will be exceeded. However, in these circumstances it is necessary to establish whether the basic restriction is fulfilled.

Depending on the frequency in order to define the basic restrictions on electromagnetic fields the following physical quantities are used (quantities that measure the magnitude or exposure rate):

- between 0 and 1 Hz, the basic restrictions are provided for magnetic flux density of the static magnetic field (0 Hz) and current density for time-varying fields up to 1 Hz, to prevent effects on the cardiovascular and central nervous system;
- between 1 Hz and 10 MHz basic restrictions are provided for current density to prevent effects on nervous system functions;
- between 100 kHz and 10 GHz provide basic restrictions on SAR to prevent body heat stress and excessive localized heating of tissues. In the frequency range between 100 kHz and 10 MHz basic restrictions are provided on both current density and SAR;
- between 10 MHz and 300 GHz, basic restrictions are provided on power density to prevent excessive tissue heating at or near the body surface area.

Basic restrictions for electric, magnetic and electromagnetic fields (0 Hz to 300 GHz) presented in table 2 are set to take into account the uncertainties related to individual susceptibility, environmental conditions, age and health status of the population.

Table 2:- Details of electric, magnetic and electromagnetic fields (0 Hz to 300 GHz)

Frequency range	Magnetic field induction (mT)	Current density (rms value) (mA/m^2)	SAR averaged over the entire body (W/Kg)	SAR localized (head and torso) (W/Kg)	SAR localized (limbs) (W/Kg)	Power density (S) (W/m^2)
0 Hz	40	-	-	-	-	-
>0-1 Hz	-	8	-	-	-	-
1-4 Hz	-	8/f	-	-	-	-
4-1.000 Hz	-	2	-	-	-	-
1000Hz-100kHz	-	f/500	-	-	-	-
100kHz-10MHz	-	f/500	0,08	2	4	-
10MHz-10GHz	-	-	0,08	2	4	-
10GHz-300GHz	-	-	-	-	-	10

The basic restriction on the current density must protect against acute exposure effects on central nervous system tissues in the head and torso and includes a safety factor. Basic restrictions for electric fields of very low frequency are based on documented harmful effects concerning the central nervous system. Such acute effects are essentially instantaneous and, scientifically, there is no reason to modify the basic restrictions for exposure of short duration. However, since the basic restriction refers to adverse effects on the central nervous system, the basic restriction may permit higher current densities in the various tissues of the body other than the central nervous system under the same exposure conditions.

Because of the electrical inhomogeneity of the body, current densities should be averaged over an area of 1 cm^2 perpendicular to the current direction. For frequencies up to 100 kHz, peak current density can be calculated by multiplying the actual value (~ 1,414). For pulses of duration tp, the equivalent frequency used in the basic restrictions should be calculated according to the formula t = 1/2·tp. For frequencies up to 100 kHz and for pulsed magnetic fields, the maximum current density associated with the pulses can be calculated from the time of rise / fall times and the maximum rate of change of magnetic induction. The induced current density can be compared with the appropriate basic restriction. All SAR values must be averaged over 6-minute intervals

The tissue mass that which must be averaged on localized SAR is 10 g of contiguous tissue. The maximum SAR so obtained is the value used for estimating exposure. These 10 g of tissue must be a contiguous mass of tissue with nearly homogeneous electrical properties. The definition of contiguous tissue mass is recognized that this concept can be used in calculating the dosimetry but may present difficulties for direct physical measurements. Simple geometry can be use such as cubic tissue mass form, provided that the calculated dosimetric quantities have constant values in relation to the standards of exposure.

The reference levels for limiting exposure are obtained from the basic restrictions, for a maximum coupling of the field and the exposed person, thus ensuring maximum protection. List of reference levels for electric, magnetic and electromagnetic fields (0 Hz - 300 GHz, unperturbed rms values) is shown in Table 3 by using relations 3.3 and 3.4 [8]. The reference levels are generally set as average values in the area in relation to body size of the exposed individual, but provided important as localized basic restrictions on exposure are not exceeded.

Table 3:- List of levels for electric, magnetic and electromagnetic fields (0 Hz - 300 GHz, unperturbed rms values)

Frequency range	Electric field intensity E (V/m)	Magnetic field intensity H (A/m)	Magnetic field induction B(μT)	Equivalent plane wave power density Seq (W/m²)
0-1 Hz	-	3.2×10^4	4×10^4	-
1-8 Hz	10.000	$3.2\times10^4/f^2$	$4\times10^4/f^2$	-
8-25 Hz	10.000	4.000/f	5.000/f	-
0,025-0,8 kHz	250/f	4/f	5/f	-
0,8-3 kHz	250/f	5	6.25	-
3-150 kHz	87	5	6.25	-
0,15-1 MHz	87	0.73/f	0.92/f	-
1-10 MHz	$87/f^{1/2}$	0.73/f	0.92/f	-
10-400 MHz	28	0.073	0.092	2
400-2000 MHz	$1.375f^{1/2}$	$0.0037f^{1/2}$	$0.0046f^{1/2}$	f/200
2-300 Ghz	61	0.16	0.20	10

In the case of frequencies from 100 kHz to 10 GHz, Seq, E2, H2, and B2 must be averaged over each period of 6 minutes. For frequencies above 10 GHz, Seq, E2, H2 and B2 must be averaged over each period of 68 / f 1.05 minutes (f in GHz). For frequencies below 1 Hz does not provide any value for E, because in this case the electric field is effectively a static electric field. For most people, any perception of discomfort due to superficial electric charges will not occur fields with intensities less than 25 kV / m. Small spark discharges that produce stress and discomfort should be avoided.

For peak values are using the following reference levels for the electric field intensity E (V / m), the magnetic field intensity H (A / m) and magnetic induction field B (T):

- for frequencies up to 100 kHz, peak reference values are obtained by multiplying the corresponding rms values (~ 1,414). For pulses of duration t is calculated using the equivalent frequency f = 1 / (2tp);
- for frequencies between 100 kHz and 10kHz, baselines peak values are obtained by multiplying the corresponding effective 10^{α} where α = [0,665 log (f / 105) + 0.176] f in Hz;
- for frequencies between 10 MHz and 300 GHz peak reference values are obtained by multiplying the corresponding rms values by 32.

In the case of simultaneous exposure to fields of different frequencies, must be the criterion on relevant electrical stimulation frequencies from 1 Hz to 10 MHz, the induced current densities, should be summed according to:

$$\sum_{i=1Hz}^{10MHz} \frac{J_i}{J_{L,i}} \leq 1$$

Where:

J_i - is the current density at frequency i
J_{Li} - is the basic restriction on the current density at the frequency from table 2

For thermal effects, relevant for the frequencies greater than or equal to 100 kHz, SAR and power densities must be added according to the relationship:

$$\sum_{i=100kHz}^{10GHz} \frac{SAR_i}{SAR_L} + \sum_{i>10GHz}^{300GHz} \frac{S_i}{S_L} \leq 1$$

For thermal effects, relevant for the frequencies greater than or equal to 100 kHz, SAR and power densities must be added according to the relationship:

Where:

SAR_i - is SAR produced at frequency i
SAR_L - is the basic restriction for SAR from table 2
S_i - is power density at frequency i
S_L - is the basic restriction power density at frequency i

To fulfill the basic restrictions, the following criteria must be applied on reference levels of field strength, such as induced current densities and electrical stimulation effects relevant for frequencies up to 10 MHz, the field must be applied to the following requirements:

$$\sum_{i=1Hz}^{1MHz} \frac{E_i}{E_{L,i}} + \sum_{i>1MHz}^{10MHz} \frac{E_i}{a} \leq 1 \quad (3.3)$$

$$\sum_{j=1Hz}^{150kHz} \frac{H_j}{H_{L,j}} + \sum_{j>150kHz}^{10MHz} \frac{H_j}{b} \leq 1 \quad (3.4)$$

Where:

Volume : 5 | Issue : 2 | February 2016 • ISSN No 2277 - 8179

Ej - is the electric field intensity at frequency i;

E_{Li} - is the reference level for the electric field intensity, from table 3;

Hj - is the magnetic field intensity at frequency j;

H_{Lj} - is the reference level for the magnetic field intensity, from table 3.

a = 87V/m and *b= 5 A/m (6,25 T).*

Compared with the standards of the International Commission on Non-Ionizing Radiation Protection (ICNIRP), which covers both occupational exposure and exposure as the general population, cutting points from amounts satisfy the conditions of exposure for the general population. Using constant values (a and b) above 1 MHz and 150 kHz electric fields to the magnetic field because the summation is based on current densities and should not be combined with thermal effect conditions. The latter is the basis for Eli HLJ at frequencies exceeding 1 MHz and 150 kHz, as shown in table 3.

If thermal effect conditions relevant for frequencies greater than or equal to 100 kHz, the following two requirements should be used to level fields:

$$\sum_{i=100kHz}^{1MHz} \left(\frac{E_i}{c}\right)^2 + \sum_{i>1MHz}^{300GHz} \left(\frac{E_i}{E_{L,i}}\right)^2 \le 1 \quad , \qquad (3.5)$$

$$\sum_{j=100kHz}^{150kHz} \left(\frac{H_j}{d}\right)^2 + \sum_{i>1kHz}^{300GHz} \left(\frac{H_i}{H_{L,i}}\right)^2 \le 1 \qquad (3.6)$$

Where:

Ej - is the electric field intensity at frequency i;

E_{Li} - is the reference level for the electric field intensity, from table 3;

Hj - is the magnetic field intensity at frequency j;

H_{Lj} - is the reference level for the magnetic field intensity, from table 3.

c = 87/f1/2 (V/m) and *d= 0,73/f (A/m)*

For currents in limbs and the contact currents, the following requirements must be used:

$$\sum_{k=10MHz}^{110MHz} \left(\frac{I_k}{I_{L,k}}\right)^2 \le 1 \quad \text{and} \quad \sum_{n>1Hz}^{110MHz} \left(\frac{In}{I_{C,n}}\right)^2 \le 1 \qquad (3.7a)$$

Where:

Ej - is the current component in limbs at frequency k;

I_{Lk} - is the reference level for current component in limbs at 45 mA;

In - is the component contact current at frequency n;

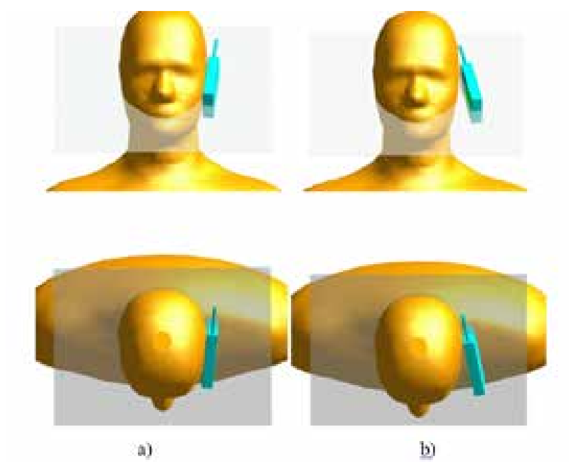
I_{Cn} - is the reference level for component contact current at frequency n, from table 3.

3. Specific absorption rate measurement on the phantom model

The so-called reference level for public exposure in the 900 MHz band specified by European guidelines is 4.5 W / m2. Exposure of the general population, due to mobile systems, is between hundreds of nW / m2 and tens of mW / m2. This wide range is mainly due to technical and environmental factors, especially the distance between the emission source and factor exposure subject. Other important sources operating in high frequency band are radio / TV transmitters with amplitude or frequency modulation. The maximum power density measured in areas accessible to the population, usually fall below 100 mW / m2. In close proximity to these powerful transmitters can measure power density values of around 300 mW/m^2. Making a comparison between analogue and digital, it can be said that exposure levels are substantially similar. Because digital television requires more transmitters per unit area, we can appreciate that exposure is higher in this case compared to analogue. Other relevant systems in this area are civil and military radar and mobile radio and private systems.

The tip of the probe shall not be in contact with the inner surface of the phantom to minimize errors in measurement. A local SAR value is highest on the inner surface of the phantom and for their assessment applies a method of extrapolation. The extrapolation is based on a polynomial approximation of the measured data of step 4 as determined by the method of least squares. Local SAR values are extrapolated from the liquid surface with a pitch of 1 mm. Measurements must be conducted within a limited time due to the battery life of the DUT.

The product is placed in positions "cheek" and "tilt" on the left or right side of the ghost and tries to frequencies of each band emission in the test conditions required, as illustrated in figure 1.



☞♓♑📫 🗁📫 Mobile phone position during measurements: a- cheek position; b- tilt position

In order to reduce the length measurement, the measuring step should be higher. It can vary between 5 mm and 8 mm. But for an accurate assessment of the maximum SAR averaged over 10 grams and 1 gram, requires a fine resolution of the scan in three dimensions. Interpolation is used to obtain a sufficiently fine resolution. The measured data are interpolated and extrapolated SAR values on a grid with a pitch of 1 mm with a "thin-plate" three-dimensional algorithm.

3.1. Performance checking for SAR dosimetric evaluation system

The measurements were made using a SAR dosimetric evaluation system produced by Satimo, Comosar Twins model.

A) Experimental conditions

Phantom model	"Twins"
DUT	Dipole
DUT position	Validation plane
Bandwidth	GSM 1800
Channel	Middle
Signal	CW

B) SAR measurement results

Frequency (MHz)	1747.400024
Relative permittivity – real part	39.903999
Relative permittivity – imaginary part	13.566000
Conductivity (S/m)	1.316957
SURFACE SAR	VOLUME SAR

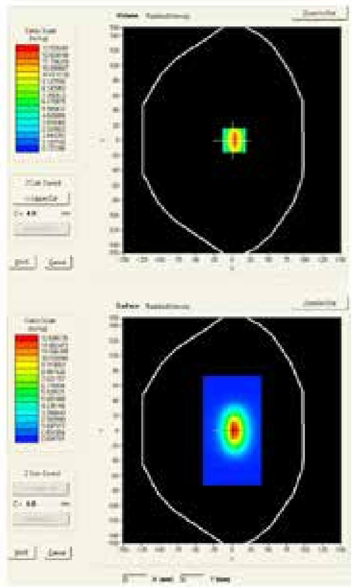


Fig. 2. SAR measurements: maximum position at X=3.00 , Y=0.00

	SAR (W/Kg)	SAR (W/Kg) Reference level	Difference (%)
SAR 10g	6.697259	6.67	0.41
SAR 1g	12.515631	12.5	0.13

Z axis scanning

Z (mm)	0.00	4.00	9.00	14.00	19.00	24.00	29.00
SAR (W/Kg)	0.0000	13.5553	7.5922	4.4304	2.6125	1.5607	0.9408

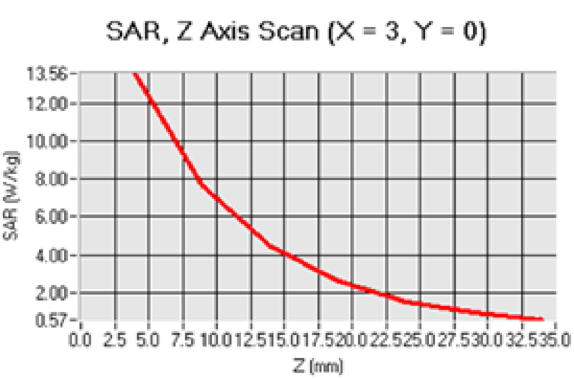


Fig. 3. Variation of maximum local SAR values

3.2. SAR measurement on the mobile phone in cheek position

A SAR measurement on the mobile phone was made and at the end result of this process it was determined of the maximum SAR value for that particular phone and this value is then compared to the exposure limits permitted under the various compliance standards in operation.

A) Experimental conditions

Phantom model	"Twins"
DUT	LG KU250
DUT position	Cheek, Left head
Bandă	GSM1800
Canale	Middle
Semnal	TDMA

B) SAR measurement results

Frequency (MHz)	1747.400024
Relative permittivity – real part	39.903999
Relative permittivity – imaginary part	13.566000
Conductivity (S/m)	1.316957
SURFACE SAR	VOLUME SAR

In order to determine SAR, a cell phone is placed next to the surface of the phantom model and turned on to transmit at the maximum power while a probe is inserted into the viscous inner mixture at various locations, measuring the radiofrequency energy that is being absorbed. The phantom model is filled with

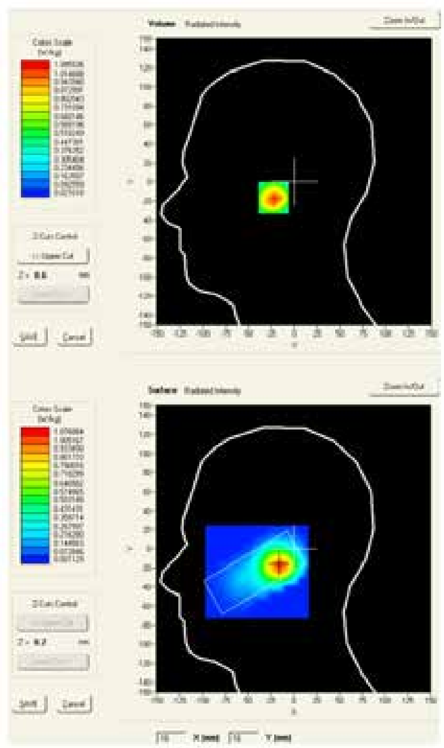


Fig. 4. SAR measurements: maximum position at X=-16.00

appropriate frequency-specific fluids with measured electrical properties (dielectric constant and conductivity). That is close to the average for gray and white matters of the brain at the frequencies of interest (1718.5 MHz).

SAR 10g (W/kg)	0.580182
SAR 1g (W/kg)	1.022678

Z axis scanning

Z (mm)	0.00	4.00	9.00	14.00	19.00	24.00	29.00
SAR (W/Kg)	0.0000	1.0858	0.6752	0.4091	0.2650	0.1725	0.1060

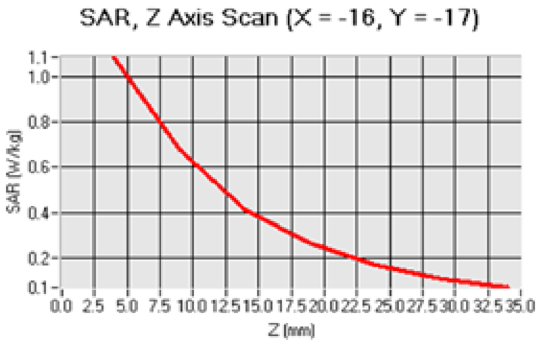


Fig. 5. Variation of maximum local SAR values

3.3. SAR measurement on the mobile phone in tilt position

A) Experimental conditions

Phantom model	“Twins”
DUT	LG KU250
DUT position	Cheek, Left head
Bandă	GSM1800
Canale	Middle
Semnal	TDMA

B) SAR measurement results

Frequency (MHz)	1747.400024
Relative permittivity – real part	39.903999
Relative permittivity – imaginary part	13.566000
Conductivity (S/m)	1.316957
SURFACE SAR	VOLUME SAR

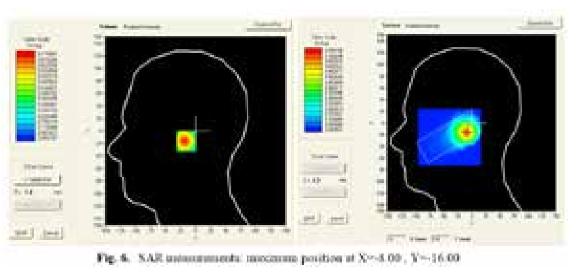


Fig. 6. SAR measurements: maximum position at X=-8.00 , Y=-16.00

SAR 10g (W/kg)	0.403744
SAR 1g (W/kg)	0.693484

Z axis scanning

Z (mm)	0.00	4.00	9.00	14.00	19.00	24.00	29.00
SAR (W/Kg)	0.0000	0.7169	0.4405	0.2829	0.1937	0.1173	0.0750

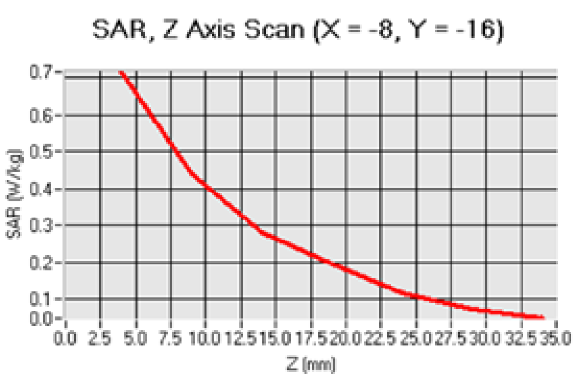


Fig. 7. Variation of maximum local SAR values

The SAR 10g is the maximum SAR value averaged on 10g which is obtained by averaging the SAR around each point in the volume and adding the nearest points till an average mass of 10g is reached with a resulting volume having the shape of a portion of sphere. The SAR 1g is estimated by averaging the local maximum SAR, adding the highest SAR volume in a given tissue till a mass of 1g is reached. The SAR (point) is the local value of SAR at every point inside the head model. The results show that by decreasing the head size the peak SAR 1g and peak SAR 10g decrease, however the percentage of absorbed power in the human head increases.

4. Conclusions

Throughout the entire existence of humanity, we cannot speak of a clear interaction between electromagnetic fields and living organisms. Could it be a human genetic programming to adapt to the electromagnetic field? Perhaps in the future will give the answer to this question, however, the systematic study of living organisms and the interaction between the electromagnetic field began in the ‘70s. The levels of low frequency interference record a decreased characteristic, which mainly comes from atmospheric electrical discharges that occur worldwide. The value of electric field intensity on clear days is about 200 volts / meter, stormy days can reach up to about 1,000 megavolt / meter.

Various specialized institutes studied the effects of electromagnetic fields and believe it is unlikely to be an association between health problems and exposure to magnetic fields. If, however, the value of the magnetic field is large there may be some biological effect, but not necessarily negative and may even be beneficial.

Regarding the interaction of electromagnetic field to the human body if it is an electric field appears so-called “antenna effect” and then appear some currents are transverse human body. It occurs here the problem of the intensity of these fields interacts with the human body. It expected current intensity arising due to the magnetic field or electric, to be lower than the intensity signals bioelectrical native when it is transferred directly into the human body. Problems can occur when these values are exceeded. If the effects on tissues that may arise exceed certain thresholds may occur muscular stimulation and for very high levels it is possible of endangering even the people lives.

The paper systematize the possible effects on biodiversity field grouping them as follows: effects due to high frequency fields, effects due to intermediate frequency fields, due to the effects of low frequency fields and effects due to static fields. Also the measurements concluded that mobile phones to brain send electromagnetic energy that can penetrate a skull on a maximum range of 3-4 centimeters and depending on phone inclination towards the head about 60% of the energy radiated by the antenna is absorbed by the brain.

By comparing the results when using mobile phones in positions *cheek* and *tilt* it can be concluded that the SAR in the inclined position of the mobile phone is reduced by over 30% compared to using the phone sticking to head and parallel to it.

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